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JOHN F. DASHIELL, *Editor*

A Re-Performance and Re-Interpretation of the Arai Experiment in Mental Fatigue with Three Subjects

By

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University of Southern California

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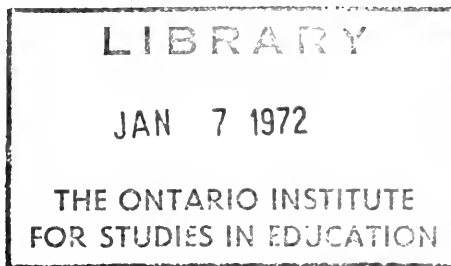
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TABLE OF CONTENTS

I. THE ONSET OF MENTAL FATIGUE

The Problem	1
Procedure	4
Results	8
Discussion	17

II. TRANSFER OF MENTAL FATIGUE

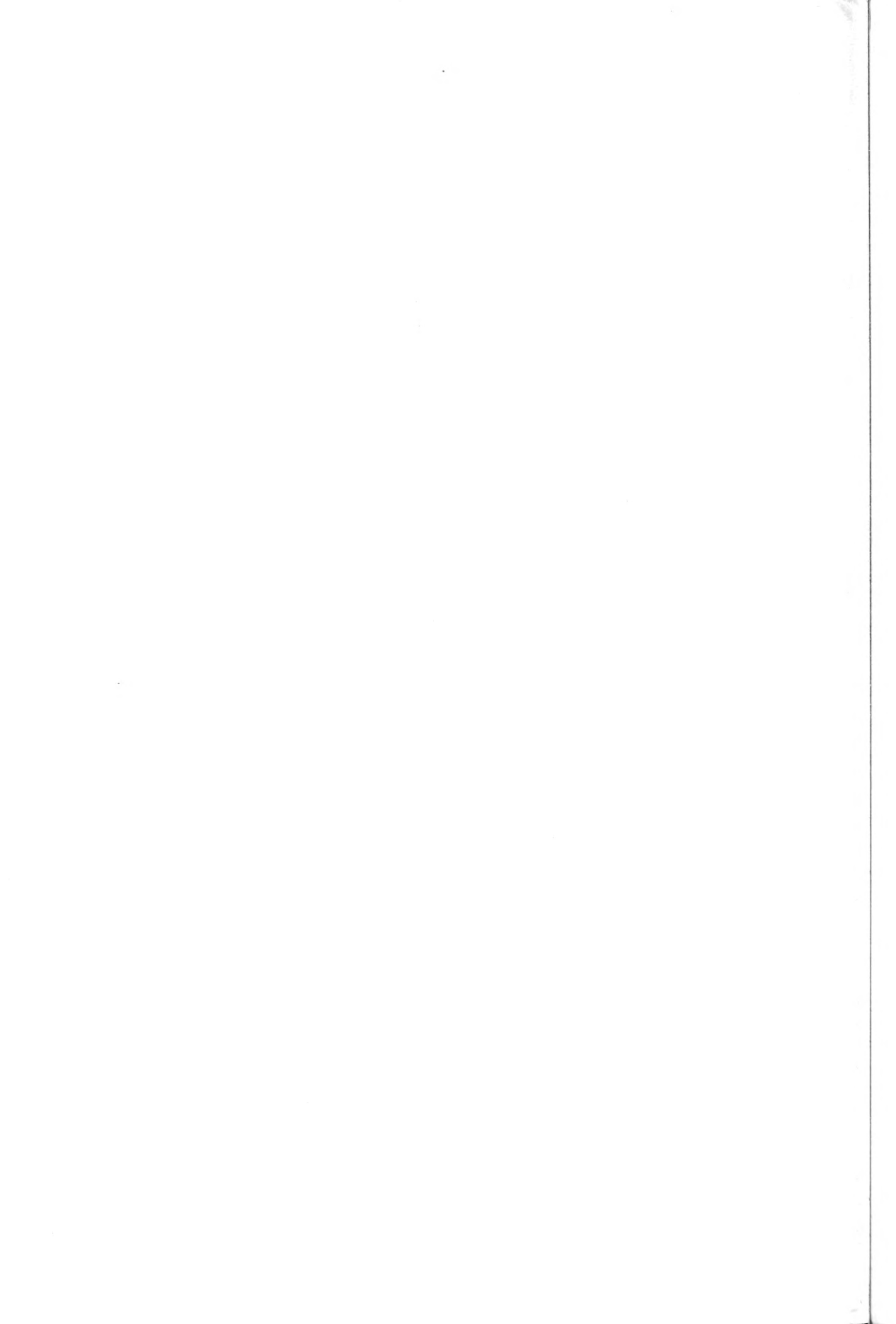
The Problem	23
Results and Interpretation	24
Summary and Conclusions	29

III. PHYSIOLOGICAL CHANGES INVOLVED IN CONTINUOUS MENTAL MULTIPLICATION

The Problem	30
Results	34
Conclusions	37

BIBLIOGRAPHY	38
--------------------	----

APPENDIX	39
----------------	----



A RE-PERFORMANCE AND RE-INTERPRETATION OF THE ARAI EXPERIMENT IN MENTAL FATIGUE WITH THREE SUBJECTS¹

CHAPTER I

THE ONSET OF MENTAL FATIGUE

THE PROBLEM

THE PURPOSE of this study was to perform again the most significant of the experiments of Tsuru Arai (1) in mental fatigue, employing three subjects instead of one as in the original experiment, to the end that parallel working data, findings, and conclusions might be compared, verified, and possibly, extended in scope and implication.

The Arai Experiment

By way of summary, Arai, in 1909, with the counsel of Thorndike (5), undertook an experimental analysis of the nature of mental fatigue. Her problem was to measure and study the effects of the continuous exercise of a difficult intellectual function, as free as possible from sensory or muscular work, at a stage when that process was, as nearly as possible, free from effects of repeated or continuous practice. Specifically, Arai's purposes were the following:

1. To determine the amount, rate, and change of rate of fatigue in the special function exercised, and
2. To discover the extent to which fatigue was transferred to certain other mental functions.

¹Marjorie Abernethy, Miriam Harker, and Zelma Langdon Huxtable, three graduate students in Educational Psychology at the University of Southern California, offered to repeat this most significant phase of Arai's experiments in mental fatigue during the spring vacation in April, 1930, under the direction of Dr. A. S. Raubenheimer, then Professor of Educational Psychology at the University of Southern California. In this account of the present experiment, the three young women, performing the mental work, are designated, respectively, Subjects X, Y, and Z.

The mental function chosen for continuous exercise, therefore, required peculiar organization to the following ends, namely:

- A. The exclusion, as completely as possible, of muscular and general physical activities;
- B. The provision of absorbingly difficult mental work;
- C. The elimination of the effects of accrued learnings through practice;
- D. The avoidance of periodical rest periods;
- E. The means of comparing results over a period of several days;
- F. The source of an objective and measurable series of results for study;
- G. The presentation of no apparent barriers to the exercise of other mental functions before and after the scheduled periods at the chosen function.

For these reasons, Arai chose the multiplication of four-place numbers by four-place numbers mentally; such, for example, as 4795 multiplied by 8364, without the assistance of pencil or paper, except for the final recording of the answer, once it had been obtained.

To cancel the effects of continuous or repeated practice, Arai frequently engaged herself during a period of months in the perfection of her techniques before she launched upon her final, consecutive four-day fatigue series.² In the

²"Fatigue series" was the name given by Miss Arai to her final, consecutive four-day ordeal of multiplying four-place numbers by four-place numbers mentally for twelve continuous hours

beginning of the practice series, as distinguished from the final, fatigue series, she multiplied the four-place numbers mentally, keeping the original figures in sight and writing down the answer only after she had obtained it completely. Considerable practice at this, however, convinced her that the task was not difficult enough, either to absorb all her conscious attention or to bring about a condition of fatigue. Accordingly, she varied her method, multiplying the numbers mentally only after she had memorized the multiplier and multiplicand. If she forgot any part of the original problem, she looked at it again until she had re-memorized it, but the time needed to work the problem was counted from the first sight of it and concluded when the answer had been written down completely.

During the week of February 24 to March 2, 1909, Miss Arai reached a point, after working 189 problems, requiring 35 hours, at which she considered practice effect very slight. She then believed she was ready for the final fatigue series, which she performed on March 3rd, 4th, 5th, and 6th, 1909. Concerning that event she has written the following account:

... "the subject performed the mental multiplication from 11 a.m. to 11 p.m. without any pauses except the two or three seconds between examples for recording time. But the subject had taken a heavier breakfast than usual at 10 a.m. and a light supper after 11 p.m. Her health was in good condition, and she slept soundly at night. The contents of her consciousness during the experiment were very simple, all desires being completely

subjected to the one desire for getting true fatigue curves."

Arai's chief attention was focused upon the increase in time required to solve one problem at the end of the mental work period, as compared with the time required at the beginning of the work period. Although the time required to work the problems, grouped by fours, fives, eights, or tens almost doubled, or in some cases more than doubled, during the twelve hours of mental work, she considered the apparent loss in efficiency due to physical weariness and consequent boredom rather than to loss in mental capacity to perform the task. Arai's essential conclusions follow:

1. Feelings of fatigue were somewhat, though far from perfectly, related to the state of mental inefficiency.
2. Spurts were not observable in fatigue curves. The gradual increase in errors, and the time required to perform the task were attributable to fatigue.
3. Difficult and disagreeable, continuous work brought about a decrease in the efficiency of the function exercised.
4. Fatigue in a special mental function, as well as in general, was slightly transferable to other functions, and the greater the fatigue, the greater the transferred fatigue.
5. Great individual differences in susceptibility to fatigue were readily observable. (This one of Arai's conclusions was obviously based upon more representative data than her lone employment at the mental multiplication of four-place numbers. Hence the data of the present experiment were especially valuable for purposes of specific verification).

each twenty-four hour period. During these periods of mental work, she did not eat or rest, but worked without respite. All shorter periods, which she spent in perfecting her technique of mental multiplication, or in overcoming "practice effect," were designated "practice periods." In this account of the present experiment, the same terminology has been used to indicate parallel periods and types of mental work.

6. Continuous mental work did not permanently injure physical tissues.

Thorndike, in his analysis of Arai's contribution to the data and understanding of mental fatigue, considered it extremely significant that a high degree of efficiency frequently accompanied "feelings" of impotency, such as extreme boredom, headache, ennui, and dizziness. On this point, he has written the following opinion:

"This, it must be remembered, by no means implies that the function was less than half as efficient at the end of the twelve hours of work as at the end of twelve hours of rest. On the contrary, the amount of percentile loss in absolute efficiency was probably very slight. For a person to be able to multiply a number like 9263 by one like 5748 without any visual, written, or spoken aids, even in fifteen, or for that matter, a hundred and fifty, minutes, implies a very high degree of efficiency. That a person can exert himself to the utmost at this very difficult work for ten or twelve hours without rest and still be able to do it, even if at the expense of twice or thrice as many minutes per example as at the beginning, means that the loss in efficiency by any absolute standard has been small.

"The zero point of efficiency in the function of mental multiplication would be 'just not to multiply a number like 3 by a number like 2 in, say, ten minutes.' We do not, of course, know just at what point between this zero and the ability to multiply a four-place number by a four-place number mentally in five minutes with only two figures in the answer wrong (as Miss Arai did at the beginning of work), we should place her ability, at the end of work to multiply a four-place by a four-place number in eleven minutes. The reader may judge for himself. It is my impression that she could, at the end of work certainly have multiplied a three-place number by a three-place number (and probably a four-place number by a three-place number) as quickly and as accurately as she had multiplied a four-place by a four-place number at the beginning, and that it would be absurd to place the efficiency of her last half hour's work in each period at less than 75 per cent of the initial efficiency." (5)

Thorndike leaves much to the reader to judge for himself concerning the actual per cent of diminution of Miss Arai's efficiency as a result of twelve hours' continuous mental multiplication on each of four consecutive days. His insistence, nevertheless, that a high quality of mental efficiency prevailed throughout the fatigue series despite increase in frequency of errors during the later hours of each twelve-hour work period, and his forthright contention that "it was his impression that she, Miss Arai, could, at the end of work, certainly have multiplied a three-place number by a three-place number . . . as quickly and as accurately as she had multiplied a four-place by a four-place number at the beginning" . . . without doubt leaves him vulnerable to contradiction.

In fact, Painter (3), apparently the only person other than Miss Arai and Subjects X, Y, and Z of the present experiment, on record as having multiplied four-place numbers by four-place numbers for experimentally defined purposes, found, contrary to Thorndike's "impression," that his ability to perform the exacting feat, gave out suddenly about three a. m. He had begun multiplying about 11 p.m. after a hard day's work. He was also unable to multiply easier numbers.

The Present Experiment

Repetition of Miss Arai's experiment, with the modifications already partially indicated, seemed highly profitable for several reasons:

First, because of the radical departure of Arai's conclusions, substantiated by so eminent an authority as Thorndike, from the common observation and belief that mental work done without rest over a long period of time results in a decrease in efficiency, that is, in a decreased

amount of work per unit of time, or an inferior quality of work, or both;

Second, because Arai's materials and results have been questioned, at least superficially, by some students of advanced psychology and also by some members of the medical profession;

Third, because of the practical bearing of a better understanding of the phenomenon of mental fatigue on mental work and mental hygiene;

Fourth, because the repetition of the experiment with three subjects instead of one, gave promise of corroborative or contradictory evidence of sufficient weight to prove or disprove the scientific validity of the original experiment, together with the findings, hypotheses, and implications which had their sources in it.

PROCEDURE

After several practice periods, varying from one to eight hours in length, analogous to Miss Arai's practice periods, spaced at intervals over several months, Subjects X, Y, and Z of the present experiment believed that they had largely overcome the effects of practice in the mental multiplication of four-place numbers. They were ready, therefore, to engage in the final four-day fatigue series, which accordingly, was scheduled for the spring vacation.

A portion of the Science Building was reserved for the use of Subjects X, Y, and Z and the laboratory technicians who performed the tests involving the metabolism, blood, urine, and respiratory equipment and apparatus. (4)

The room provided for the mental multiplication was a spacious laboratory on the third floor. It had large windows on two sides, which afforded excellent light and ventilation. The room was furnished with a long work table and comfortable chairs, some with side-arms,

some without. Each subject had at her disposal a comfortable cot, pillows, blankets, and a small writing table. The cots were placed at some distance from one another in order that the movements of one subject would be as little disturbance to the other two subjects as possible. Drinking water was kept near each subject throughout the four days. Precautions had been taken to prevent noises and other types of disturbances about the halls of the building. After the first day, a trained nurse came to the laboratory frequently, though as unobtrusively as possible, to note signs of serious fatigue or possible illness.

The program for each subject during the four-day fatigue series consisted of the following:

Each subject might eat breakfast as she desired, there being no prescription on content or quantity.

The approximate time for arrival at the laboratory was 5 a.m. For ten minutes thereafter, each subject reclined to compensate for climbing the steps to the second story. After a urine specimen had been obtained, the metabolic rate established on the Sanborn Graphic Metabolic Machine, the blood taken for the blood count, and the respiratory movements graphed, the subject went directly to an adjoining office for a series of psychological tests. All this required approximately 60 minutes.

Immediately following the foregoing preliminaries, each subject proceeded to the problem-solving laboratory for the twelve-hour period of mental multiplication of four-place numbers by four-place numbers. At the close of the twelve-hour marathon, each subject returned to the office, again took psychological tests, proceeded to the metabolic machine, the respiratory apparatus, and provided other urine and blood speci-

mens. Urine specimens were obtained not only before and after each metabolism test, but also at needed intervals during the twelve-hour problem solving periods. After the evening's checking of respective blood and urine specimens, metabolic rates, and respiratory movements, each subject was free to go to her dinner and night's rest. As much sleep as possible was advised. This was the general procedure followed on each of the four days of the fatigue series.

Aside from the differences in type and number of mental tests used, and the addition of the physiological tests described above, before and after each of the 12-hour periods of the four-day fatigue series in the present experiment, the same general methods paralleled those of Arai's original experiment. Marjorie Abernethy, Miriam Harker, and Zelma Langdon Huxtable, three graduate students in Advanced Educational Psychology at the University of Southern California, offered to act as subjects under the direction of Dr. Albert S. Raubenheimer, then Professor of Educational Psychology at the University of Southern California. Dr. F. M. Baldwin, Professor of Zoology, also of the University of Southern California, agreed to investigate the effects of the continuous exercises of the selected mental function upon certain physiological processes.

Severally defined, the purposes of the present experiment were the following:

1. To repeat Arai's major experiment as closely and critically as possible, employing three subjects instead of one;
2. To study more completely the effects of mental work upon other functions tested before and after each of the twelve-hour periods of the consecutive four-day fatigue series;

3. To study the effects of (a) each twelve-hour period; and (b) the total four-day fatigue series, upon certain physiological functions and conditions, namely:

- A. Metabolic rate
- B. Blood changes
- C. Urinal changes
- D. Respiratory measurements and changes (6)
- E. Pulse, temperature, weight

4. To analyze more critically than Miss Arai had done, if possible, the effects upon the work curve of individual reactions to "feelings" of fatigue, of distractions from one's surroundings, of one's own conflicting mental states, and of bodily conditions and changes.

During the final fatigue series, each of the Subjects, X, Y, and Z was provided with identical stacks of 4 by 6 inch slips of paper, each bearing correspondingly identical problems, such as

$$\begin{array}{r} 5967 \\ \times 4857 \\ \hline \end{array}$$

Each slip of paper was numbered in the upper right corner on both sides.

As in the case of Arai, the subject recorded the time by her watch, which had a second hand, in the upper left hand corner of the slip of paper as soon as she looked at the problem. The hour, minute, and second were recorded as follows: 11-8-15, which meant, eight minutes, fifteen seconds after eleven o'clock. The subject then proceeded to memorize the two four-place numbers. As soon as she had them sufficiently well in mind, she turned the slip of paper over, worked the problem mentally without help of pencil, recorded the answer only when it had been obtained in its entirety; and last of all set down the time when she completed writing the answer. She then proceeded to the next

CHART 1. SAMPLE PROBLEM
INDICATING NUMBER OF OPERATIONS EMPLOYED IN MENTAL MULTIPLICATION OF ONE
FOUR-PLACE NUMBER BY ANOTHER FOUR-PLACE NUMBER¹

Let any problem, such as 6793 multiplied by 9438 be represented by the eight X's as follows:									
	X	X	X	X	...	8	operations were allowed for memorizing the eight digits comprising the original problem.		
	X	X	X	X					
		1	4	4	2	...	11	operations for first partial product (required in processes of multiplication, carrying, adding, recall). Numerals represent number of operations needed to obtain respective digits in partial product.	
			1	4	4	4	2	...	15
				1	4	4	4	2	...
					1	4	4	4	2
1	4	4	4	4	2	...	15	operations for fourth partial product.	
3	4	5	0	0	5	2	1	...	32
							4	operations added for final recording and recall of completed answer.	
<hr/>									
							100	total operations needed in solving problem.	

The unanimity with which Subjects X, Y, and Z agreed upon the number of operations involved in multiplying a four-place number by a four-place number, each Subject employing her own unique mental methods, both in the solution of the problem and in her estimation of how she had done it, was one of the most convincing phenomena of the entire study. Although Subject Y alone followed a method almost identical with that of Miss Arai, each of the three Subjects estimated that she needed 96 to 100 operations in solving a problem. The itemization indicated above accounts for the 96 operations actually needed in solving the problem mentally. Four more operations, a modest reckoning, were then allowed by Subjects X and Y for the final memory feat of recalling and recording the completed answer, making a total of 100 operations. Subject Z's method follows.

¹ This was approximately the method used by Subjects X and Y in the present experiment, and by Arai in her original experiment.

example. The problem, out of sight after it was memorized, sometimes escaped ir- retrievably. In such event, the subject might turn the card over, and re-mem- orize the problem, the original time re- maining unaltered. At the very outset of the experiment, the importance of a record of "feelings" of fatigue was recog- nized. Subjects X, Y, and Z were, ac- cordingly, encouraged, both by Arai's findings and by the express purposes of the present experiment, to take time out from problem solving whenever they were, severally, impressed by any change in feelings, whether for better or worse, and to write down words, phrases, sentences, or paragraphs descriptive of the subjective states.

Each of the three subjects in the pres- ent experiment worked her problems entirely independently, using her own characteristic methods and habits of

memorizing, retaining, solving, recall- ing, and recording answers and reac- tions. For this reason, each individual's record must stand as a unique experi- ment in many significant respects. Never- theless, much data was comparable and adequately salient to justify the con- clusions which follow.

The conversion of the gross number of problems solved into the smallest pos- sible units of work was a significant con- tribution of the present experiment. These, in turn, were converted into a common time base, namely, the number of seconds per operation. Whenever er- rors occurred, allowance was made by adding the number of seconds which, hypothetically, would have been re- quired to correct the errors at the rate of progress prevalent at that given hour of the fatigue series. Although Thorn- dike conceded that both his and Miss

CHART 2. SUBJECT Z'S STEP BY STEP SOLUTION OF THE MENTAL MULTIPLICATION OF A FOUR-PLACE NUMBER BY A FOUR-PLACE NUMBER USING HER OWN UNIQUE METHOD

Given the number to multiply by	5 8	3 7	6 9	4 2				
The answer is	4	7	1	6	0	2	8	8
(Obtained by Subject Z after 2 minutes, 55 seconds mental work; the first 30 seconds were spent in memorizing the problem. The numbers were then hidden from sight and the solution completed men- tally without aides of any kind, except for the final recording of the answer on a piece of paper.)								
Here is the step by step process:								
Step 1	memorizing problem...	8	operations	Step 27	memorize 0288 for ans..	1	operations	
" 2	2×4 equals 8.....	3	"	" 28	12 to carry.....	1	"	
" 3	memorize the 8 for ans..	1	"	" 29	9×5 equals 45.....	3	"	
" 4	0 to carry.....	1	"	" 30	plus 12 equals 57.....	2	"	
" 5	2×6 equals 12.....	3	"	" 31	6×8 equals 48.....	3	"	
" 6	plus 0 to carry.....	1	"	" 32	plus 57 equals 105.....	2	"	
" 7	4×9 equals 36.....	3	"	" 33	7×3 equals 21.....	3	"	
" 8	plus 12 equals 48.....	2	"	" 34	plus 105 equals 126.....	2	"	
" 9	memorize 88 for answer.	1	"	" 35	memorize 60288 for ans.	1	"	
" 10	4 to carry.....	1	"	" 36	carry 12.....	1	"	
" 11	2×3 equals 6.....	3	"	" 37	7×5 equals 35.....	3	"	
" 12	plus 4 equals 10.....	2	"	" 38	plus 12 equals 47.....	2	"	
" 13	4×7 equals 28.....	3	"	" 39	3×8 equals 24.....	3	"	
" 14	plus 10 equals 38.....	2	"	" 40	plus 47 equals 71.....	2	"	
" 15	6×9 equals 54.....	3	"	" 41	memorize 160288 for ans.....	1	"	
" 16	plus 38 equals 02.....	2	"	" 42	carry 7.....	1	"	
" 17	memorize 288 for answer	1	"	" 43	5×8 equals 40.....	3	"	
" 18	9 to carry.....	1	"	" 44	plus 7 equals 47.....	2	"	
" 19	2×5 equals 10.....	3	"	" 45	memorize 7106288 for ans.....	1	"	
" 20	plus 9 equals 19.....	2	"	" 46	memorize 47160288 for ans.....	1	"	
" 21	4×8 equals 32.....	3	"	" 47	write down final ans....	1*	"	
" 22	plus 19 equals 51.....	2	"					
" 23	3×9 equals 27.....	3	"					
" 24	plus 51 equals 78.....	2	"					
" 25	6×7 equals 42.....	3	"					
" 26	plus 72 equals 120.....	2	"					
Grand Total.....100								

* In order to fix the number of operations needed in solving a problem at 100, Subject Z added only one additional operation for recalling and recording the final answer. Subjects X and Y added four operations at this point for the same obvious reason.

Arai's corrections for errors were "of course, arbitrary and any reasonable allowance would give substantially the same general curve," the method described here, on the other hand, yields a ratio between speed and accuracy which can be logically and scientifically defended.

Arai added ten seconds per digit error in the answer by way of penalty; Thorn-dike, sensing the need for a greater penalty during the later hours of the day when work was proceeding more sluggishly, added twelve per cent of the time required per example for each

wrong figure more than two in any answer. But quite unaccountably, he subtracted twelve per cent for each wrong figure less than two in any answer. Actually, a mistake of one digit in an answer, usually required on the average a long chain of mental operations in order to correct and replace that digit mentally. From the tabulation of the number and placement of the frequencies of incorrect digits in the answers of Subjects X, Y, and Z, the mean and mode of the incorrect digits were found to fall respectively, upon the digits placed fifth and fourth from the left. The sample

problem in Chart 1, indicates the number of operations performed in obtaining each digit in the answer. The replacement of one such incorrect digit required usually, not ten seconds or even 12% of the time used in solving the problem, but, on the average, 20 operations. Frequently, the replacement of one digit required the re-working of the entire problem, often including laborious recall by feeble association, to make the original problem mentally available. The more weary the subject, the longer the time required to go back and reconstruct the long, tedious process mentally. Consequently, it was with overwhelming conviction of the justice and accuracy of the procedure, that the mean number of operations estimated as necessary to correct a digit error was placed at 20, the

weighted value of the fifth digit from the left.

In estimating the number of seconds required to replace an incorrect digit, therefore, the number of seconds actually required for working the problem was divided by five, which was the ratio of the number of operations necessary in solving the problem (100) to the weight (20) of the mean placement of the fifth digit from the left.

RESULTS

1. In the present experiment, increased speed in the mental multiplication of four-place numbers, despite the effects of fatigue, distinguished the performances of all Subjects, X, Y, and Z. This phenomenon of increased speed was totally absent from the work of Arai;

TABLE I
ESSENTIAL DATA OF FATIGUE SERIES BASED ON NUMBER OF PROBLEMS SOLVED

Subject		Total Problems Solved	Problems Totally Correct	Problems Containing Error	Percent Problems Totally Correct	Percent Problems Containing Error
Arai	1st day	67	21	46	45.7	54.3
	2nd day	67	14	53	26.4	73.6
	3rd day	67	14	53	26.4	73.6
	4th day	67	10	57	17.5	72.5
	Totals	268	59	209		
X	1st day	80	38	42	47.5	52.5
	2nd day	101	54	47	53.5	46.5
	3rd day	114	37	77	32.5	67.5
	4th day	115	33	82	28.7	71.3
	Totals	410	162	248		
Y	1st day	63	33	30	52.4	47.6
	2nd day	79	33	46	41.8	58.2
	3rd day	92	34	58	37.0	63.0
	4th day	92	33	59	35.9	64.1
	Totals	326	133	193		
Z	1st day	80	52	28	65.0	35.0
	2nd day	97	50	47	51.5	48.5
	3rd day	100	37	69	34.9	65.1
	4th day	100	43	57	43.0	67.0
	Totals	383	182	201		

TABLE 2
ESSENTIAL DATA OF FATIGUE SERIES BASED ON NUMBER OF OPERATIONS PERFORMED

Subject		Total Operations Performed	Total Operations Correct	Total Operations Incorrect	Percent Operations Correct	Percent Operations Incorrect
Arai	1st day	6700	6599	101	98.49	1.51
	2nd day	6700	6573	127	98.10	1.90
	3rd day	6700	6573	127	98.10	1.90
	4th day	6700	6545	155	97.68	2.32
	Totals	26800	26290	510		
X	1st day	8000	7930	70	99.12	.88
	2nd day	10100	10016	84	99.17	.83
	3rd day	11400	11250	141	98.76	1.24
	4th day	11500	11357	143	98.76	1.24
	Totals	41000	40562	438		
Y	1st day	6300	6253	47	99.25	.75
	2nd day	7900	7824	76	99.04	.96
	3rd day	9200	9087	113	98.77	1.23
	4th day	9200	9097	103	98.88	1.12
	Totals	32600	32261	339		
Z	1st day	8000	7953	47	99.40	.60
	2nd day	9700	9620	80	99.18	.82
	3rd day	10600	10408	132	98.76	1.24
	4th day	10000	9910	90	99.10	.90
	Totals	38300	37951	349		

in fact, its possibility was ruled out on the ground that preliminary practice periods had eliminated improvement due to further practice. In the present experiment, however, Subjects X, Y, and Z, despite preliminary practice periods equivalent to, and analogous with those of Arai, increased their speed significantly during the fatigue series. Reasons were, undoubtedly, due to tacit competition among the three subjects, excessive nervous stimulation, a desire to make a better showing than Arai had done, or possibly, to superior ability to perform mental multiplication. As cases in point, Table 1 indicates that Arai performed the mental multiplication of 67 problems on each of the four days of the fatigue series; Subject X, on the other hand, increased her speed from 80 problems on the first day to 111 and 115 respectively, on the third and fourth

days. Subject Y, increased from 63 problems on the first day to 92 on each of the third and fourth days, and Subject Z raised her total daily output from 80 on the first day to 106 and 100 respectively, on the third and fourth days.

2. Increased speed often, though not invariably, was associated in the present experiment, with a decrease in the number of problems solved with answers totally correct, especially in the later hours of a 12-hour work period. The effects of fatigue or of continuous mental work, therefore, would seem to be associated with an increase in the per cent of error, though not with the increase in quantity of output. Table 1 shows this point emphatically. Subject X, for example, scored 38 totally correct problems out of 80 worked on the first day, and only 33 totally correct out of 115 worked on the fourth day; Subject Y,

33 right out of 63 on the first day, and 33 right out of 92 worked on the fourth day; Subject Z, 52 right out of 80 worked on the first day, and 43 right out of 100 on the fourth day. Miss Arai, by way of comparison, scored 21 totally correct problems out of 67 on the first day, then dropped to only 10 totally right out of 67 on the fourth day.

3. Increased speed in the present experiment, tended to be accompanied by an increase in per cent of erroneous answers, but not necessarily in a diminution of totally correct output in terms of operational units performed. Table 2 presents the essential data of the present experiment, based on the number of operations performed. Subject X, for example, though falling in per cent of accuracy from 99.12 on the first day to 98.76 on the fourth; nevertheless, increased her total output of correct operations from 7930 on the first day to 11,357 on the fourth day; Subject Y's per cent of accuracy fell from 99.25 on the first

day to 98.88 on the fourth day, but her total output of correct operations increased from 6253 on the first day to 9097 on the fourth day; Subject Z, analogously, decreased from 99.10 per cent correct operations on the first day to 99.10 per cent on the fourth, but her total output of correct operations increased from 7953 on the first day to 9910 on the fourth day.

4. Evaluation of this functional relationship between speed and accuracy must remain a mathematical hypothesis in the conclusions of the present experiment. Table 3 for each of the Subjects: Arai, X, Y, and Z, presents both the actual number of seconds required per operation in the mental solution of a four-place multiplication problem, and the corrected time for operational errors, that is, the actual time plus the additional time, which would, hypothetically, have been required to have performed the operations without error. This seems to be the nearest approach to a solution

TABLE 3—(ARAI)
FATIGUE IN THE MENTAL MULTIPLICATION OF FOUR-PLACE NUMBERS CALCULATED IN
SECONDS PER OPERATION BY HOUR PERIODS

Seconds required per operation and seconds added to compensate for operational errors at rate of work during any given hour

Hour	First Day		Second Day		Third Day		Fourth Day		Average	
	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time
1	3.37	4.51	3.50	4.76	2.93	3.84	3.00	4.26	3.20	4.34
2	4.37	5.24	4.56	5.34	3.70	5.18	3.69	4.80	4.08	5.14
3	4.63	5.43	4.21	6.25	4.45	5.47	3.86	4.96	4.29	5.53
4	4.44	5.77	4.70	6.58	4.52	5.20	4.85	7.44	4.63	6.27
5	6.52	8.34	5.76	7.83	4.41	5.73	4.43	5.77	5.28	6.92
6	7.05	11.63	6.37	8.40	5.90	7.38	5.92	8.52	6.31	8.98
7	8.79	12.31	6.48	9.08	7.30	9.86	5.28	7.19	6.96	9.61
8	7.26	10.61	7.39	9.24	7.05	12.34	6.65	9.98	7.09	10.54
9	6.91	8.84	7.70	9.24	5.35	7.49	4.48	6.28	6.11	7.96
10	7.06	8.75	6.29	9.72	4.28	6.34	5.31	11.94	5.74	9.19
11	6.79	7.81	6.00	9.84	6.53	10.78	5.26	9.99	6.15	9.61
12	9.72	13.60	8.53	13.09	5.87	10.16	5.43	6.89	7.39	10.94
First Two Hours	3.87	4.88	4.03	5.05	3.32	4.51	3.35	4.53	3.64	4.74
Last Two Hours	8.26	10.71	7.27	11.47	6.15	10.47	5.35	8.44	6.77	10.28
Seconds Loss in Efficiency	4.39	5.83	3.24	6.42	2.83	5.96	2.00	3.91	3.13	5.54

TABLE 3—(SUBJECT X)
FATIGUE IN THE MENTAL MULTIPLICATION OF FOUR-PLACE NUMBERS CALCULATED IN
SECONDS PER OPERATION BY HOUR PERIODS

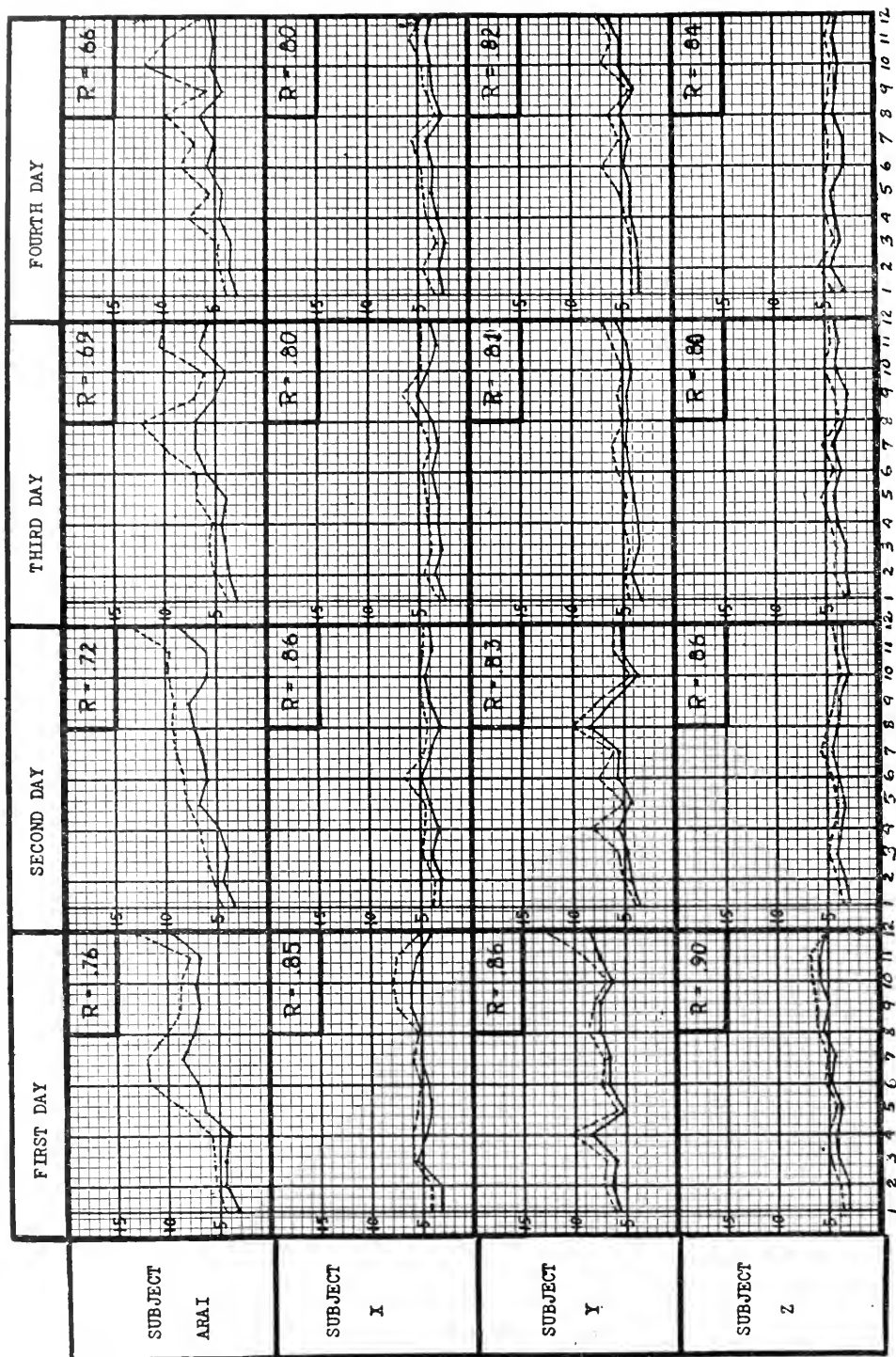
Actual seconds required per operation and corrected time for operational errors at
rate of work during respective hour periods

Hour	First Day		Second Day		Third Day		Fourth Day		Average	
	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time
1	4.13	4.50	3.34	3.87	2.61	3.05	2.79	3.16	3.22	3.65
2	4.19	4.61	3.31	3.64	3.59	3.62	3.30	4.62	3.60	4.12
3	5.65	5.84	3.86	4.63	2.78	3.62	2.68	3.18	3.99	4.32
4	4.80	6.03	3.38	4.57	3.07	3.92	3.18	4.05	3.61	4.65
5	4.44	5.45	4.04	4.44	3.22	4.21	3.73	4.67	3.86	4.69
6	4.56	5.22	4.05	5.61	3.84	4.35	3.72	4.95	4.27	5.03
7	5.27	5.87	4.34	4.66	3.10	3.89	4.31	5.82	4.26	5.06
8	5.27	5.27	3.36	4.23	3.78	4.79	2.81	3.51	3.81	4.45
9	6.04	7.40	4.20	4.78	5.16	6.36	3.63	4.20	4.78	5.71
10	6.19	8.17	4.60	4.90	4.47	4.66	3.94	4.64	4.80	5.62
11	5.64	7.71	3.07	4.76	3.61	4.95	4.25	5.84	4.37	5.82
12	4.07	5.28	4.05	4.51	3.92	4.98	4.02	4.82	4.02	4.00
First Two Hours	4.16	4.56	3.33	3.76	3.10	3.34	3.05	3.89	3.41	3.89
Last Two Hours	4.86	6.50	4.01	4.64	3.77	4.97	4.14	5.33	4.20	5.36
Seconds Loss in Efficiency	.70	1.44	.68	.88	.67	1.63	1.09	1.44	.79	1.49

TABLE 3—(SUBJECT Y)
FATIGUE IN THE MENTAL MULTIPLICATION OF FOUR-PLACE NUMBERS CALCULATED IN
SECONDS PER OPERATION BY HOUR PERIODS

Actual seconds per operation and corrected time for operational errors at rate of
work during respective hour periods

Hour	First Day		Second Day		Third Day		Fourth Day		Average	
	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time
1	5.68	6.06	3.68	3.76	3.25	4.55	3.20	4.02	3.98	4.58
2	6.23	7.06	4.29	5.03	4.03	4.75	3.20	4.08	4.46	5.23
3	5.02	6.90	4.89	5.45	3.69	4.43	3.47	4.00	4.49	5.22
4	8.23	10.29	5.67	8.12	3.86	4.92	3.00	4.78	5.44	7.03
5	5.13	5.86	4.18	4.83	3.08	4.78	4.20	5.40	4.40	5.22
6	6.56	7.35	5.70	7.41	4.20	5.58	4.88	6.68	5.36	6.83
7	6.53	7.32	5.38	6.10	4.88	6.03	4.55	5.20	5.34	6.16
8	7.22	8.66	8.10	10.01	4.60	4.90	5.04	6.33	6.24	7.50
9	7.20	7.87	6.28	7.70	4.81	5.50	3.87	4.35	5.56	6.45
10	6.40	6.66	3.88	4.56	4.13	5.08	5.11	6.08	4.88	5.82
11	7.46	8.95	5.24	6.20	4.46	5.68	5.14	5.88	5.58	6.78
12	8.35	12.27	5.11	6.39	5.59	7.00	6.28	7.22	6.33	8.24
First Two Hours	5.96	6.56	3.90	4.40	3.64	4.65	3.20	4.05	4.11	4.91
Last Two Hours	7.91	10.61	5.18	6.34	5.03	6.54	5.71	6.55	6.96	7.51
Loss in Effi- ciency	1.95	4.05	1.19	1.94	1.39	1.80	2.42	2.50	2.85	2.60



Seconds per operation

FIG. 1. Speed curves in the mental multiplication of four-place numbers. Actual speed curves of fatigue series by hour periods compared with hypothetical speed curves corrected for errors. Subjects: Arai, X, Y, and Z. (Plotted from data of Table 3)

HOURS OF CONTINUOUS MENTAL WORK

Unbroken Line—Actual Speed Broken Line—Hypothetical Speed Corrected for Errors
R—Ratio of Actual Speed to Hypothetical Speed Corrected for Errors

TABLE 3—(SUBJECT Z)
FATIGUE IN THE MENTAL MULTIPLICATION OF FOUR-PLACE NUMBERS CALCULATED IN
SECONDS PER OPERATION BY HOUR PERIODS

Actual seconds per operation and corrected time for operational errors at rate of
work during respective hour periods

Hour	First Day		Second Day		Third Day		Fourth Day		Average	
	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time	Sec- onds	Corr'd. Time
1	3.22	3.51	2.93	3.36	2.71	3.16	3.48	4.36	3.09	3.60
2	3.29	3.91	3.58	3.94	3.31	4.23	4.55	5.59	3.68	4.42
3	4.47	4.62	4.36	4.98	3.08	4.01	3.30	3.96	3.80	4.89
4	4.40	5.06	3.93	4.61	3.76	4.60	4.00	4.90	4.02	4.79
5	3.92	4.37	3.49	4.36	4.25	5.31	3.55	4.08	3.80	4.53
6	4.80	5.20	4.26	4.79	3.51	4.21	3.39	3.86	3.99	4.52
7	4.50	5.25	4.70	5.80	4.36	5.10	3.25	3.64	4.20	4.95
8	5.60	5.97	4.16	5.11	3.00	3.60	4.26	4.68	4.26	4.84
9	5.13	6.33	3.87	4.35	2.97	4.15	2.85	3.30	3.71	4.53
10	5.85	6.55	2.83	3.29	4.22	5.16	3.70	4.60	4.15	4.90
11	5.80	6.96	3.53	3.84	3.52	4.68	4.05	4.96	4.23	5.11
12	5.00	5.00	3.61	4.64	4.00	4.40	3.45	4.14	4.02	4.55
First Two Hours	3.25	3.71	3.26	3.65	3.01	3.70	4.02	4.98	3.39	4.01
Last Two Hours	5.40	5.98	3.57	4.24	3.76	4.54	3.75	4.55	4.13	4.83
Loss in Efficiency	2.14	2.27	.31	.59	.75	.84	.27*	.43*	.74	.82

* These gains in efficiency of the last two hours of the Fourth Day for Subject Z appeared only this once during the repeated experiment and not at all in Miss Arai's data.

of the relationship between speed and accuracy which can be made in the interpretation of results in the present experiment. Figure 1 shows, graphically, this relationship. Though *R*, representing the ratio of actual speed to hypothetical speed corrected for errors, is merely a mathematical concept, the numerical value which it expresses in each instance, accorded with observable factors influencing speed and accuracy.

5. A unique contribution of the present experiment was the conversion of the gross number of problems solved into the smallest possible units of work to be described and discussed below (pp. 16ff.). These, in turn, were converted into a common time base, specifically, the number of seconds per operation (Table 3).

6. Daily work curves for Subjects X, Y, and Z, based upon the actual number of seconds per operation, as well as upon the hypothetical number of seconds per

operation, which would have been required had errors been corrected by hour periods, showed a distinct leveling off in slope, as contrasted with Miss Arai's work curves, which under analogous conditions of mathematical interpretation, rose notably (Figure 1).

7. Daily work curves, representing the time in minutes required to solve successive sets of four problems with allowances made for errors, after the methods of Arai and Thorndike, also depicted graphically the significant difference in the nature and general direction of the work curves of Subjects X, Y, and Z as compared with Arai's (Figure 2).

8. Despite conclusive, objective evidence that feelings of intense dislike, ennui, boredom to the extent of headache and illness, dizziness, nervous irritability, and physical and muscular weariness were accompanied by some decrease in mental efficiency, one would not venture a guess as to what extent the

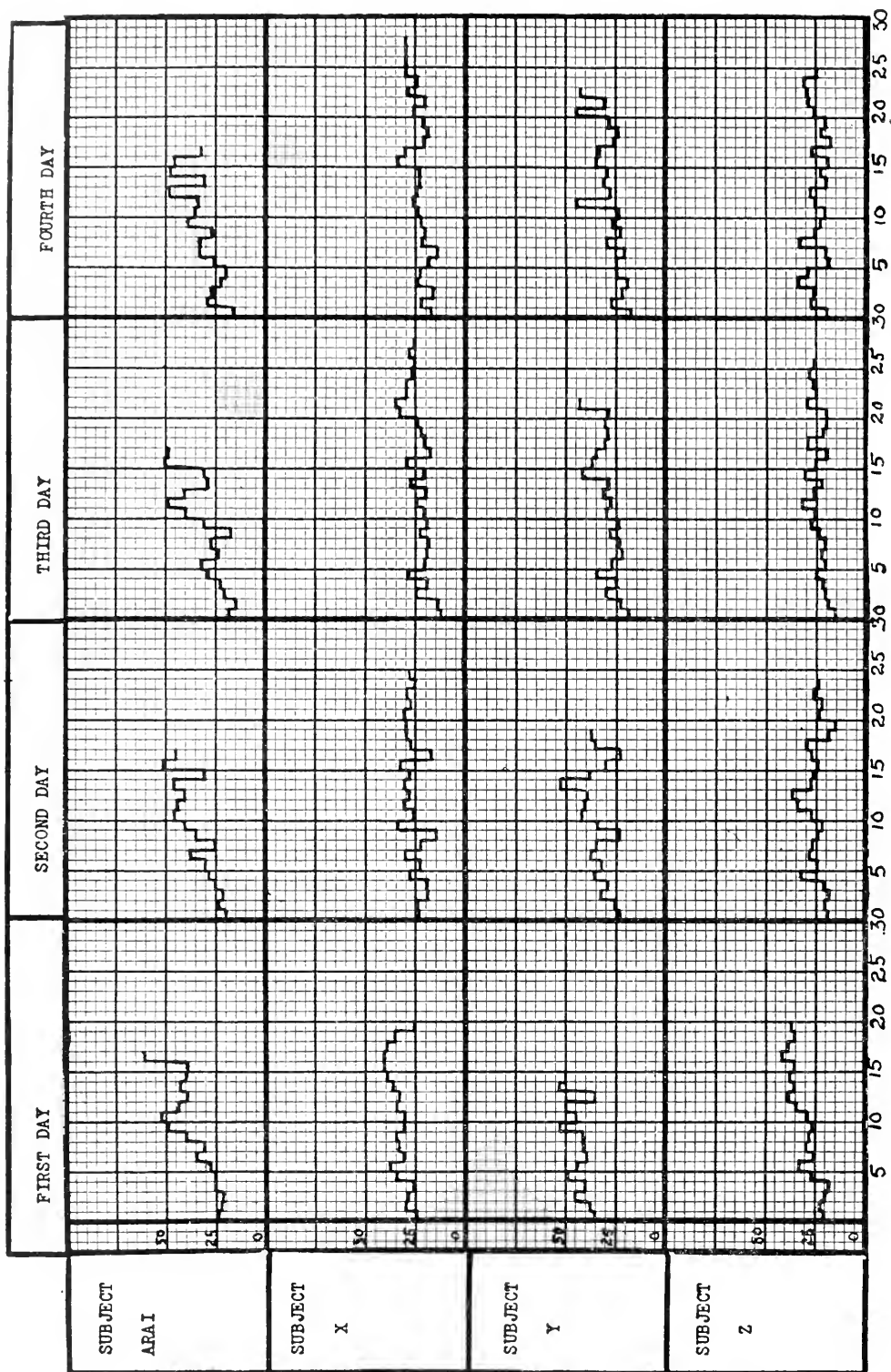


FIG. 2. Work curves in the mental multiplication of four-place numbers. Time in minutes required to solve successive sets of four problems with allowances made for errors after Arai's method.
Subjects: Arai, X, Y, and Z. (Plotted from Data of Table 4)

NUMBER OF SETS OF FOUR PROBLEMS MULTIPLIED MENTALLY IN 12 HOUR PERIODS

Vertical Division Lines—Beginnings of New 12 Hour Periods Short Horizontal Lines—Successive Sets of Four Problems

TABLE 4—(ARAI)
 FATIGUE IN THE MENTAL MULTIPLICATION OF FOUR-PLACE NUMBERS
 Time required in minutes, with allowances for errors, for successive sets of four
 examples multiplied mentally by Miss Arai, March 3-6, 1909.¹

Sets of Four	March 3	March 4	March 5	March 6	Average
1	23.6	20.7	19.3	16.5	20.0
2	23.3	24.5	16.5	29.6	23.9
3	23.2	23.5	20.9	28.5	23.4
4	26.1	25.9	22.8	23.0	24.6
5	25.8	27.8	28.3	20.2	26.8
6	27.3	31.4	31.7	26.2	29.4
7	34.3	37.3	24.0	33.6	34.0
8	31.3	24.9	27.5	33.8	29.4
9	40.0	35.0	17.1	26.7	30.9
10	49.8	41.5	31.0	38.6	40.0
11	52.2	45.8	39.1	35.6	42.5
12	43.8	44.6	48.1	34.1	44.2
13	37.9	41.8	41.0	47.0	41.4
14	42.5	46.5	27.9	29.8	36.2
15	39.7	31.1	28.3	47.1	36.6
16	39.0	52.0	50.0	45.6	46.7
17	(3 pr. 62.1)*	(3 pr. 44.4)*	(3 pr. 49.1)*	(3 pr. 32.9)*	(3 pr. 47.1)*
First Eight Problems	46.9	45.2	35.8	46.1	43.9
Last Eight Problems (Excluding incom- plete groups marked with star)	78.7	83.1	78.3	92.7	83.3
Minutes Loss in Effi- ciency	31.8	37.9	42.5	46.6	39.4

* Incomplete sets of problems.

¹ Tsuru Arai, *op. cit.*, p. 38 f., also p. 86.

decrease was attributable to divided attention or to mental fatigue per se; significant objective evidence was present, however, in the comparison of the average time required to work the first four or eight problems each morning with the average time required to work the last four or eight problems in the evening. In most instances, the subjects started the day feeling fresher and more mentally fit than they felt any other time of the day. The last eight problems, on the other hand, were usually solved under conditions of severe physical and nervous strain. Comparisons at this point show that Subject X worked the first eight problems in 42.1 minutes, taking the average time required to work the first eight problems over the four-day fatigue series (Table 1), and making allowances for errors after the methods of Arai and Thorndike. The last eight

problems, worked under similar conditions, however, required 57 minutes for Subject X. The difference, 14.6 minutes, represented, undoubtedly, mental and physical fatigue. Corresponding figures for Subject Y were 52.2 minutes for the first eight problems, and 80.0 minutes for the last eight, the difference, 27.8 minutes, representing fatigue. Subject Z's first eight problems required 41.6 minutes as contrasted with 52.9 minutes consumed in solving the last eight, the fatigue difference amounting to 11.3 minutes. Arai's comparable record was 43.9 minutes for the first eight problems and 83.3 minutes for the last eight, leaving 39.4 minutes as her fatigue difference.

9. Another interesting comparison which undoubtedly revealed the effects of fatigue, lay in the actual seconds per operation required during the first two

TABLE 4—(SUBJECT X)

FATIGUE IN THE MENTAL MULTIPLICATION OF FOUR-PLACE NUMBERS

Time required in minutes, with allowances for errors by Arai's method for successive sets of four examples multiplied mentally by Subject X, April 16-19, 1930

Sets of Four	April 16	April 17	April 18	April 19	Average
1	24.4	22.8	12.2	17.2	19.1
2	31.5	23.9	14.5	23.1	23.3
3	28.7	18.4	25.8	16.8	22.4
4	25.3	19.8	19.8	23.8	22.2
5	34.6	27.9	29.4	22.8	28.7
6	38.6	23.2	21.8	17.5	25.3
7	30.7	30.3	20.1	13.3	23.6
8	32.2	23.5	18.0	22.5	24.1
9	32.9	14.2	23.1	20.3	22.6
10	31.2	34.8	18.6	22.8	26.9
11	30.9	25.3	21.5	23.4	25.3
12	35.0	31.7	25.2	25.3	29.3
13	34.4	28.8	21.8	24.6	27.4
14	37.2	30.0	27.3	23.5	29.7
15	40.1	27.8	20.5	23.3	27.9
16	40.8	32.4	29.3	34.6	34.3
17	40.9	16.7	17.6	30.2	26.4
18	39.3	27.6	21.3	20.9	27.3
19	34.9	28.1	23.5	18.8	26.3
20	25.3	29.5	24.7	20.1	24.9
21		31.0	32.8	26.3	30.0
22		26.9	35.8	19.8	27.5
23		28.4	29.5	28.8	28.9
24		25.4	30.0	23.4	26.3
25		28.3	26.8	29.4	28.2
26		(1 pr. 8.1)*	25.9	29.7	27.8
27			28.6	29.5	29.1
28			26.2	29.8	28.0
29			(2 pr. 9.4)*	(3 pr. 20.3)*	20.3
First Eight Problems	55.9	46.7	26.7	40.3	42.4
Last Eight Problems	60.2	53.7	54.8	59.3	57.0
(Not including broken groups marked with star)					
Minutes Loss in Efficiency	4.3	7.0	28.1	19.0	14.6

* Incomplete sets of problems.

hours of the day with similar data for the last two hours. Subject X, for example, required 3.41 seconds per operation during the first two hours, on the average, but by the end of the day, she was requiring 4.20 seconds per operation, losing .79 second per operation due to fatigue. Subject Y, requiring 4.11 seconds per operation on the average during the first two hours, was consuming 6.96 seconds per operation at the end of the day, losing 2.85 seconds per operation by reason, it would appear, of fatigue. Comparably, Subject Z's average

time per operation increased from 3.39 seconds in the first two hours of the morning to 4.13 seconds per operation in the evening, indicating a loss of .74 second per operation by reason of the prolonged mental work. These figures do not take into account corrections in time as penalty for errors. Arai's time per operation increased from 3.64 seconds for the first two hours in the morning to 6.77 seconds per operation in the last two hours of the afternoon, showing a loss of 3.13 seconds per operation as a result, undoubtedly, of fatigue.

These figures, representing the differences in the time required to work problems of equivalent difficulty in the first two hours of the twelve hour work periods, as contrasted with the time required to do equivalent work during the last two hours of the twelve hour work periods, provided, perhaps, the most convincing evidence in the present experiment that fatigue or its equivalent generally affected efficiency of performance after long periods of uninterrupted mental work. An exception, nevertheless, appeared even in this otherwise convincing chain of evidence, for Subject Z on the fourth day of the fatigue series performed more efficiently during the last

two hours than she had during the first two hours (Table 3).

DISCUSSION

1. The extent and significance of the effects of fatigue in the present experiment seemed to be involved inextricably with the functional relationship of speed and accuracy. Moreover, since the human factor of relative unpredictability cannot be overlooked in an interpretation of this functional relationship, some discussion of logical and philosophical factors, though lacking scientific validity in the strictest sense, are none the less appropriate.

Which, indeed, was actually the su-

TABLE 4—(SUBJECT Y)

FATIGUE IN THE MENTAL MULTIPLICATION OF FOUR-PLACE NUMBERS

Time required in minutes, with allowances for errors by Arai's method, for successive sets of four examples multiplied mentally by Subject Y, April 16-19, 1930

Sets of Four	April 16	April 17	April 18	April 19	Average
1	35.9	24.7	17.7	17.6	24.0
2	37.9	25.1	22.3	27.3	28.2
3	46.3	32.4	31.1	22.5	33.1
4	40.5	29.6	24.4	21.0	28.9
5	49.3	35.8	35.6	25.2	36.5
6	44.3	33.4	27.6	25.7	32.8
7	35.3	37.1	23.3	20.6	29.1
8	37.9	35.5	24.7	29.9	32.0
9	41.3	23.5	28.5	23.2	29.1
10	53.3	35.3	23.7	26.2	34.6
11	45.4	43.4	30.7	24.9	36.1
12	50.7	41.6	28.8	44.5	41.4
13	36.3	40.1	31.5	27.1	33.8
14	53.9	52.8	29.3	31.2	41.8
15	50.8	38.3	42.0	30.5	40.4
16	(2 pr. 29.9)*	30.2	37.3	35.8	34.4
17		22.8	35.2	34.3	30.8
18		35.1	31.0	25.8	30.6
19		36.4	28.5	25.7	30.2
20		(3 pr. 30.6)*	20.7	28.1	28.0
21			28.5	45.0	36.8
22			43.6	31.8	37.7
23			(3 pr. 26.3)*	42.3	42.3
First Eight Problems	73.8	49.8	40.0	44.0	52.2
Last Eight Problems	104.7	71.6	72.1	74.1	80.0
(Excluding incomplete groups marked with stars)					
Minutes Loss in Efficiency	30.9	21.8	32.1	29.2	27.8

*Incomplete sets of problems.

TABLE 4—(SUBJECT Z)
FATIGUE IN THE MENTAL MULTIPLICATION OF FOUR-PLACE NUMBERS
Time required in minutes, with allowances for errors by Arai's method, for successive sets of four examples multiplied mentally by Subject Z, April 16-19, 1930

Sets of Four	April 16	April 17	April 18	April 19	Average
1	19.2	19.7	16.5	19.8	18.8
2	22.8	20.7	19.2	28.3	22.8
3	21.5	19.3	20.2	27.2	22.1
4	18.3	21.5	20.5	34.3	23.7
5	27.2	33.2	25.2	27.9	28.4
6	33.4	24.7	21.8	19.3	24.8
7	25.0	27.3	23.1	19.3	23.8
8	20.3	27.2	21.7	33.8	28.0
9	28.3	24.7	24.5	25.8	25.8
10	27.3	22.5	27.1	23.0	25.0
11	28.7	27.3	25.7	20.0	25.4
12	35.1	34.0	32.7	25.0	31.7
13	38.7	30.9	26.0	27.1	32.2
14	36.3	27.8	22.2	18.3	26.2
15	37.2	27.2	30.6	22.7	29.4
16	36.0	24.1	24.1	18.9	25.8
17	42.8	27.3	19.5	27.0	29.2
18	38.3	30.6	30.3	17.3	29.1
19	34.1	17.6	21.3	20.8	23.5
20	34.9	16.5	19.5	20.7	22.9
21		23.8	19.5	25.8	23.0
22		23.7	30.0	27.5	27.4
23		25.8	25.8	27.2	26.3
24		25.6	26.2	28.3	26.7
25		(1 pr. 4.6)*	27.9	24.6	26.3
26			26.6		26.6
27			(2 pr. 12.8)*		
First Eight Problems	42.0	40.4	35.7	48.1	41.6
Last Eight Problems (Excluding starred incomplete groups)	69.0	51.4	54.5	52.9	52.9
Minutes Loss in Efficiency	27.0	11.0	18.8	4.8	11.3

* Incomplete sets of problems.

prior product when considered in the light of the practical life situation—increased speed with slightly greater per cent of error, or decreased speed with slightly greater per cent of accuracy—would probably depend upon the seriousness of consequences of errors in the nature of the work being done. For example, an error in setting a time bomb would be far more significant than an error in counting vitamin tablets into a bottle. It is quite conceivable that an employer might prefer an employee to work at top speed in the latter instance, considering an occasional mistake unimportant. But speed would cease to be

the paramount consideration in the preparation of the time bomb where accuracy was, primarily, the issue of life or death. In as much as Subjects X, Y, and Z were not told to excel in either speed or accuracy at the expense of the other factor, ultimate decision as to which was the superior: increased speed with greater per cent of error, or decreased speed with greater per cent of accuracy, is outside the bounds of present conjecture.³

³ Subject X expressed the opinion, during the present experiment, to Subjects Y and Z that she considered continuous speed and total quantity output more important to the general problem of mental fatigue and the establishment of fatigue curves than mere accuracy of product.

The per cent of accuracy for the amount of work done, according to common methods of figuring absolute accuracy, for two of the subjects, namely, Y and Z, was highest on the first day (Table 1); for X, on the second day. If, however, one takes into account the total number of operations involved in obtaining the answer in the multiplication of a four-place number by a four-place number, mentally, the actual total of correct, and of incorrect operations as well, was greatest on the days when the greatest number of problems was solved (Table 2).

It is noteworthy, at this point, that Arai, though solving only 67 problems each day, scored a higher per cent of error throughout the fatigue series than any one of the Subjects X, Y, or Z in the present experiment (Figure 1 and Table 1).

2. Through the construction of work curves for Subjects X, Y, and Z, contrasting the mean actual time required in seconds per operation by hour periods with the mean hypothetical time in seconds per operation by hour periods which would have been necessary to have performed all the same operations correctly, was discovered the rather startling fact that Subject Z had worked more efficiently during the last two hours of the fourth day than she had during the first two hours of that day (Table 3). This was the only occurrence of this phenomenon in the work of Subjects X, Y, and Z, or Arai.

For purposes of comparison, similar curves to those described in the preceding paragraph for Subjects X, Y, and Z were constructed to represent Arai's problem solving during the fatigue series. Although no record of the exact placement of digit errors in her work was available, the actual number of errors per problem, a matter of record,

afforded the necessary data. The laws of chance, normally would have operated for the placement of Miss Arai's errors as they had for the errors of Subjects X, Y, and Z of the present experiment. Comparison of her work curves with those of Subjects X, Y, and Z makes graphic many contributions of this experiment (cf. Figure 2 and Table 4), the most noteworthy being the leveling off of the curves of the three Subjects, X, Y, and Z during the third and fourth days of the fatigue series, as contrasted with the distinct rise on each day of the fatigue series in the work curves of the former.

3. Perhaps, the most revealing comparisons, in view of the work done by Thorndike in the interpretation of Arai's findings, were those representing the grouping of problems in the fatigue series by the time required to work each successive set of four problems. Table 4 and Figure 2 present these findings for both Arai's original investigation and the present experiment. Again one's attention is arrested by the difference in the general direction and nature of the work curves of Subjects X, Y, and Z and Arai during the last two days of the fatigue series. On superficial analysis, they appear contradictory. In reality, they probably indicate gradations of effort, due in part to the competitive situation set up in the present experiment, of emotional and nervous stimulation, and possibly, of ability to perform mental multiplication, rather than mental fatigue per se. If Thorndike, indeed, considered Arai's findings inimical to the usual notion of mental fatigue despite the decrease in efficiency as the twelve-hour periods of the fatigue series progressed, how much greater cause would he have had for this argument from the work curves of Subjects X, Y, and Z!

4. Finally, certain conclusions should

be added by way of general information, even warning.

Any serious question as to whether or not the mental multiplication of four-place numbers by four-place numbers is physically and mentally possible over a period of many hours, may be answered once and for always in the affirmative. Nor is the ability a characteristic of the Oriental mind or of any other racial classification. It may well be an ability which is not possessed by all individuals, though generalizations on this point are open to question. The process is exceedingly exacting and tedious; and above all else, requires a power of mental concentration which is rare, even among university students and professors. Hence, one will seldom meet an individual who has succeeded in multiplying one four-place number by another mentally.

Because the process of multiplying four-place numbers mentally does require mental discipline of the most exacting quality, any physical discomfort or ailment, any distraction, physical or emotional, renders the task almost unbearable. One must not only possess complete and rigorous control of the mental processes involved in the mathematics of solving the problems; but, also, of the power to subject all interferences, whether they emanate in the environment or in one's physical condition, to the complete control of the mental. Subjects Arai, and X, Y, and Z all claimed to be in good health; moreover, the physical tests given the three latter in the present experiment bore out that claim with respect to them, at least. One might, in fact, readily question the ability of any person in poor physical health to overcome physical, environmental, and emotional distractions sufficiently to perform the mental multiplication of

four-place numbers by four-place numbers for any prolonged period.

Though Thorndike makes the statement that "the zero point of efficiency in the function of mental multiplication would be 'just not to multiply a number like 3 by a number like 2 in, say ten minutes'," one would hesitate to become fatigued to that point, especially under the nervous tension stimulated by the competitive nature of the present experiment. In fact, the condition which Thorndike describes might better be designated as mental collapse, or, at best, mental irresponsibility, as in sleep. Certainly, as long as one were responsible at all, one would be able to multiply 2 by 3. It is at this point that a subject who has performed the feat of mental multiplication of four-place numbers over a period as long as the fatigue series of this experiment, is tempted to admonish anyone, who contemplates long periods of mental concentration that will bring about fatigue to the point of inability to perform the simplest of mathematical operations, as cited by Thorndike, that such a condition is to be avoided. If one might drop off to a healthy, untroubled sleep, as in the instance cited by Painter, the after-effects would probably be little harmful. If, on the other hand, one should become so nervously stimulated that healthy sleep were impossible, prolonged continuance at the task might conceivably, bring on mental or nervous collapse. Whether a victim so afflicted would ever completely recover is matter of some speculation; certainly, it would be the height of folly to take the chance. Parenthetically, it should be added that none of the Subjects, X, Y, Z, or Arai, according to her record, ever approached the point of "zero efficiency" as defined by Thorndike. But the difficulty and annoyance,

which were suffered at various periods during the fatigue series—no subject entirely excepted—on account of headaches, emotional upsets, lack of sleep, nervous excitability, and other disturbances, were adequate warning to healthy individuals, particularly to Subjects X, Y, and Z, that one less robust in health, or more completely exhausted nervously, might suffer serious consequences.

5. Lastly, attention may be called to the interesting fact that every subject, including Arai, by way of protecting herself from the exacting concentration of the task, at the time, prepared for herself an ever so subtle means of partial escape. That is, every subject *seemed innately* to avoid the utmost mental exertion possible and prepared some way to relieve herself, even if ever so slightly. Not one of the subjects, undoubtedly, would have admitted any deliberate plan or overt intention to lessen the strain at the time of the experiment, but in retrospect the implicit design was evident in the strategy of each one of the subjects, including Arai. For example, Arai planned in her experiment to work exactly 67 problems each day on the ground that she had reached the limit of her ability to improve through continued practice. Subjects X and Z, on the other hand, though they had practiced as much or more than Arai, discovered on the first day of the present experiment, that under the stress of competition, they had not stretched to the utmost, their ability to multiply four-place numbers mentally. Though all three subjects in the present experiment did speed up almost unbelievably during the last three days of the fatigue series, each still held on to some escape mechanism. Subject X, for example, anxious to perform the greatest quantity of

work possible in the given time, claimed that exact accuracy was not paramount in the ascertaining of the true nature of the mental work curves, which, it was hoped, would be established. In other words, she escaped mentally through the avoidance of the tedious checking of possible errors; instead, she dismissed any uncertainty which did not actually block her further progress and proceeded to the next problem. Subject Y, from the very beginning of the experiment, on account of her mother's anxiety lest she not be strong enough physically to withstand the ordeal, refused to compete with Subjects X and Z. This was to her a means of partial escape; nor would one have criticized the wisdom of it. In fact, throughout the fatigue series, she was competing rather with Miss Arai's record and her own previous day's record, than with the records of Subjects X and Z. Subject Z, devising her own peculiar subterfuge, contended that accuracy was more significant, perhaps, than quantity in the performance of the mental task; therefore, when the pressure of distractions and the confusion of possible errors became too great, she simply "drew a blank" in her mind, so to speak, and worked the problem over again from the beginning. The fourth day of the fatigue series presented an example of her unintentional strategy. Realizing that she would probably survive the fatigue marathon by this time, and believing Subject X was proceeding too rapidly to avoid a disproportionate per cent of error, she settled down to the performance of the kind of work which would satisfy her. As a consequence, and quite unwittingly, she performed more efficient work during the final two hours of the fourth day than during the first two hours of that day.

Notwithstanding that Subjects X, Y,

and Z more than corroborated the contentions of both Arai and Thorndike that a high standard of mental efficiency was maintained throughout the fatigue series and that few if any objective mental effects of fatigue were measurable. Subjects X, Y, and Z, as Arai had done, admitted their awareness of a general development of fatigue, which did involve the nervous system, and presumably, to some extent, the higher brain cells. One is reminded that the preservation of the human organism depends occasionally upon that increment of mental perseverance which exerts itself in the emergency of physical exhaustion. Any at-

tempt to reduce that increment to its last margins, under severe mental strain, as in competition, would appear to involve the dangerous chance of mental as well as physical collapse. Nevertheless, Arai's original experiment and the present experiment of Subjects X, Y, and Z bore definite witness that healthy individuals can exert mental effort on occasion far beyond that ordinarily exercised by students or by mental workers on the "job" without significant transfer of fatigue, except in a few inconclusive instances—to other mental functions, the evidence in support of which, follows in Chapter II.

CHAPTER II

TRANSFER OF MENTAL FATIGUE

THE PROBLEM

THE PRESENT study was concerned with the effects of the continuous mental multiplication of four-place numbers by four-place numbers for four consecutive days, as previously described in Chapter I, upon the efficiency of other mental functions, tested before and after each of the twelve-hour days of the fatigue series.

The Tests Used

Most of the tests used were novel, that is, they were used only once, but in a few instances, the same test was given both before and after a twelve-hour mental multiplication period, in order that the function of memory might be studied. One test of mechanical ability was included in the battery of tests, for the purpose of measuring motor coordination as well as mental activity.

A series of mental tests, requiring approximately twenty-five minutes, was given before and after each twelve-hour period of mental multiplication on each of the four days of the fatigue series. One series of tests was kept constant throughout the experiment, namely, Wylie's Opposites Test (7). Comparable tests of this series were given every day, both before and after the twelve-hour mental multiplication periods. The tests given were the following:

The Tests Given

1. Wylie's Opposites Test

A list of thirty-five words was given for which the subject wrote an antonym beginning with a prescribed letter. The letter was "a" in Form A, etc. Forms A, B, C, and D were standardized as comparable to each other.

Forms I, L, r, and t contained twenty words.

2. Thorndike Intelligence Examination for High School Graduates

Tests 1a and 1b from Forms C and AA

Reading Comprehension

Test 8 from Forms B and C

Number Progression

3. Macquarrie Test for Mechanical Ability

This test included seven short tests: Tracing, 50 sec.; Tapping, 30 sec.; Dots, 30 sec.; Copying, 21½ min.; Location, 2 min.; Blocks, 2½ min.; and Pursuit, 21½ min.

4. L. L. Thurstone and Thelma Gwinn Thurstone Psychological Examination for High School Graduates and College Freshmen

Artificial Language, 1927 and 1928 editions

Arithmetic Test, 1928 edition

Completion Test, 1928 edition. Blanks in sentences were to be filled with an appropriate word containing the number of letters indicated by a figure in parenthesis before the blank.

The Experiment

On each of the four days of the fatigue series the three subjects arrived at the laboratory at about five A. M., after eating breakfast. Following approximately eight minutes of physiological testing, each subject repaired to the office where she started the battery of tests assigned for that day and hour. After the completion of the tests, which consumed about 25 minutes, each subject went immediately to the work laboratory for her 12-hours of mental multiplication. At the close of the 12-hour period, the subjects returned, individually, at once to the office for another battery of psychological tests, prepared for the evening of that day. After this they, severally, appeared for the repetition of the physio-

TABLE 5
TESTS USED IN THE EXPERIMENT

Date	Time	Test	Before 12-hour period	After
4 '16 '30	5 min. 15 min.	Opposites Test Thorndike Reading Test	Form A Test 1a Forms C and AA	Form B Test 1b
4 '17 '30	5 min. 2 min. 10 min.	Opposites Test Opposites Test Completion Test	Form B Form f Same both times	Form A Form l
4 '18 '30	5 min. 2 min. 50 sec. 30 sec. 30 sec. 2½ min. 2 min. 2½ min. 2½ min.	Opposites Test Opposites Test Macquarrie Test for Mechanical Ability Tracing Tapping Dotting Copying Location Blocks Pursuit	Form C Form r Same both times	Form D Form t
4 '19 '30	5 min. 10 min. 9 min. 1½ min.	Opposites Test Artificial Language Arithmetic Reasoning Number Progression	Form D 1928 ed. Odd Prob. Form C	Form C 1927 ed. Even Prob. Form B

This table should be read as follows: On April 16, 1930, before the 12-hour period of mental multiplication, Form A of the Opposites Test was taken. Form B was taken after the 12-hour period. Five minutes was allowed for the test.

logical tests of the morning. The subjects were then free to go home, eat dinner, and retire.

The tests given before and after each of the 12-hour periods of mental multiplication have been summarized in Table 5.

RESULTS AND INTERPRETATION

First Day

In the morning, Form A of the Opposites Test was taken by the three Subjects, X, Y, and Z, and in the evening Form B of the same test, standardized as comparable to Form A, was taken. The Scores of Subjects X and Z were 11 and 9 points lower, respectively, in the evening after the 12-hour period of mental multiplication than in the morning, preceding the work period. Subject Y's score showed no change. This decrease in scores for Subjects X and Z would ap-

pear to indicate a decrease in alertness in the evening. Table 6 indicates the scores made on the several tests before and after the 12-hour periods of work, and the positive or negative gains for the first and second days of the fatigue series.

In order to test the effects of difficult mental work on reading ability, Tests 1a and 1b from the Thorndike Intelligence Examination for High School graduates were given, respectively, before and after the 12-hour period of mental multiplication. All the subjects scored lower after the 12-hour period of mental work, the decrease ranging from 8 to 14 points. These differences seemed to indicate some transferred fatigue. (See Table 6.)

Second Day

Forms A and B of the Opposites Test were reversed, Form B being given in the

TABLE 6
TEST SCORES FIRST DAY, APRIL 16, 1930

Subject	Before	After	Difference
<i>The Opposites Test</i>			
	<i>Test A</i>	<i>Test B</i>	
X	72	61	-11
Y	58	58	0
Z	69	60	-9
<i>Reading Comprehension</i>			
	<i>Test 1a</i>	<i>Test 1b</i>	
X	17	11	-6
	18	10	-8
	35	21	-14
Y	13	9½	-3½
	16	11	-5
	29	20½	-8½
Z	15	9	-6
	11	13	+2
	26	22	-4

TEST SCORES SECOND DAY, APRIL 17, 1930

<i>The Opposites Test</i>			
	<i>Test B</i>	<i>Test A</i>	
X	71	73	+2
Y	52	66	+14
Z	71	79	+8
	<i>Test f</i>	<i>Test l</i>	
X	48	51	+3
Y	39	41	+2
Z	45	47	+2
<i>Completion Test</i>			
X	50	60	+10
Y	62	68	+6
Z	60	62	+2

morning before the mental multiplication period, and Form A after the 12-hour work period. On this day, the scores of all three subjects were higher after mental work than before. Subject Y, whose score did not change on the first day, increased her score after the mental work on the second day, 14 points. The fact that the tests were identical with those given on the previous day, though given in reverse order on the second day, might seem to discount the increase in scores, except for the repetitive element, which was common to

both Forms A and B. If any advantage had been gained through recency, it should have favored Form B, as it was this form that had been given in the evening of the first day, immediately preceding, at an interval of only 11 hours; whereas, the interval between the two Forms of Test A was 36 hours. Possibly the test, Form A, taken in the morning of the first day, was more easily remembered because of the rested condition of the subjects at the beginning of the fatigue series.

On the second day, also, Forms f and l of the Wylie Opposites Test were administered: Form f in the morning, and Form l in the evening. (See Table 6.) On these tests all three Subjects made slightly higher scores after the mental multiplication than they had before.

In the Completion Test taken from the Thurstone Psychological Examination, which was given in identical form both before and after the 12 hours' mental work, all three subjects scored somewhat higher the second time the test was taken. Memory, undoubtedly, facilitated the second performance. Certainly the effects of transferred fatigue, if they were present, were not apparent as measured by any of the measuring devices used at the close of the second day of mental work.

Third Day

On this day scores for Subjects X and Z on Forms C and D of the Wylie Opposites Test were decidedly higher in the evening than they had been in the morning (Table 7). Subject X's drop in score on these tests, both before and after mental work, has not been explained. The results of the other tests taken by Subject X on this same day are average, as compared with her other records and those of the other two subjects.

TABLE 7
TEST SCORES THIRD DAY, APRIL 18, 1930

Subject	Before	After	Difference
<i>The Opposites Test</i>			
	<i>Test C</i>	<i>Test D</i>	
X	47	58	+ 11
Y	71	70	- 1
Z	72	86	+ 14
	<i>Test r</i>	<i>Test t</i>	
X	42	33	- 9
Y	37	27	- 10
Z	46	33	- 13

<i>Macquarrie Test for Mechanical Ability</i>										
	Subject X			Subject Y			Subject Z			Time
	Be- fore	After	Differ- ence	Be- fore	After	Differ- ence	Be- fore	After	Differ- ence	
Tracing	41	25	- 16	44	36	- 8	42	46	+ 4	50 seconds
Tapping	44	38	- 6	46	44	- 2	46	46	0	30 "
Dotting	23	21	- 2	26	23	- 3	23	23	0	30 "
Copying	70	67	- 3	33	17	- 16	58	53	- 5	2½ minutes
Location	40	40	0	36	37	+ 1	33	37	+ 4	2 "
Blocks	25	24	- 1	18	19	+ 1	18	18	0	2½ "
Pursuit	28	31	+ 3	28	29	+ 1	26	20	- 6	2½ "

TEST SCORES FOURTH DAY, APRIL 19, 1930

<i>The Opposites Test</i>			
	<i>Test D</i>	<i>Test C</i>	
X	71	66	- 5
Y	60	73	+ 4
Z	88	77	- 11
<i>Artificial Language</i>			
X	72	56	- 16
Y	73	72	- 1
Z	46	37	- 9
<i>Arithmetic Reasoning</i>			
X	32	20	- 12
Y	20	16	- 4
Z	20	16	- 4
<i>Number Progression</i>			
X	8	10	+ 2
Y	3	5	+ 2
Z	6	6	0

In the cases of all three subjects, Form r, taken in the morning, was considerably higher than Form t, taken in the evening. These tests, Forms r and t, however, had not been standardized as comparable with each other as Forms A, B, C, and D had been standardized as comparable among themselves. Therefore, the differences resulting from Forms r and t may have been due to the

inherent quality of the tests rather than to the effects of fatigue on the subjects.

On the third day, the Macquarrie Test for Mechanical Ability was given both before and after the 12-hour period of mental work. Five-sevenths of the scores for all three subjects were lower after the mental work period. Of the scores that were higher, all but one represented performance of activities easily remem-

bered from the morning to the evening performance, such, for example, as the location of letters in a square. There were seven separate tests in the Macquarie Mechanical Aptitude battery, and the three subjects taking the tests made twenty-one different scores. Of these, fifteen scores were lower or identical in the evening as compared with the morning scores. Three of the six remaining scores were higher by 1 point only in the evening, one was 3 points higher, and two, 4 points higher. Only two scores were significantly lower in the evening. They may have signified a lessening of sensory-motor coordination. The erratic nature of the scores made on the third day, at the close of the 12-hour period of mental work, as compared with the scores made at the beginning of that day, and also, with scores made both before and after work on the two preceding days, may have indicated some transfer of fatigue.

Fourth Day

On the last day of the fatigue series, the differences in scores between the morning and evening performances on the Wylie Opposites Test, showed a wide range. Form D was repeated this time in the morning, immediately following its administration on the evening before; and Form C was repeated in the evening, having been given originally in the morning of the preceding day.

The scores of all three subjects on Form C, when taken in the morning of the third day, were somewhat lower than the scores of the three subjects on the same Form C taken after mental multiplication on the fourth day. Strangely enough, the scores of all three subjects on Form D, taken after mental work on the third day, as compared with the scores of the three subjects on the same

Form D, taken before the mental multiplication period on the fourth day, did not reflect consistently the recovery from fatigue which might have been anticipated after the night's rest.

Morning and evening scores on the fourth day, on the Wylie Opposites Test, varied from an improvement of 4 points by Subject Y to a loss of 11 points by Subject Z.

In the Artificial Language test, also taken from the Thurstone Psychological Examination, the evening scores were all lower than those made in the morning, but the differences ranged from 1 to 16 points loss.

Scores on the Arithmetic Reasoning Test from the Thurstone Psychological Examination were also lower in the evening than in the morning. Subject X dropped 12 points and Subjects Y and Z, 4 points each.

In the Number Progression Test from the Thorndike Intelligence Examination for High School Graduates, identical forms of which were given before and after the mental multiplication period, scores were either identical or slightly better after the 12-hour period of mental work than before. Memory appeared to have offset the effects of fatigue, if fatigue were present.

The results of the Artificial Language and Arithmetic Reasoning Tests, on the fourth day of the fatigue series, appeared to indicate that novel mental tasks requiring a high degree of organization and initiative, were affected in some measure by fatigue. That this fatigue was probably cumulative, was evidenced by instability and unaccountable variation in the scores of both morning and evening on the third and fourth days.

The Wylie Opposites Test

Table 8 shows a complete synopsis of

TABLE 8
THE OPPOSITES TEST BY WYLIE

A list of 35 words was given for which the subject wrote an antonym beginning with a prescribed letter.
Tests A, B, C, D—5 minutes—35 words
Tests f, l, r, t—2 minutes—20 words

Test Scores

Day	Subject X			Subject Y			Subject Z		
	Before	After	Difference	Before	After	Difference	Before	After	Difference
1	A 72	B 61	-11	A 58	B 58	0	A 69	B 60	-9
2	B 71	A 73	+2	B 52	A 66	+14	B 71	A 79	+8
	f 48	l 51	+3	f 39	l 41	+2	f 45	l 47	+2
3	C 47	D 58	+11	C 71	C 70	-1	C 72	D 86	+14
	r 42	t 33	-9	r 37	t 27	-10	r 46	t 33	-13
4	D 71	C 66	-5	D 69	C 73	+4	D 88	C 77	-11

Median score for Seniors in college was 240, that is, the sum of the scores of tests A, B, C, and D. For superior adults with special training in English, the median score of 290 is suggested by Wylie.

Scores of Tests Taken for the First Time Only

	Subject X	Subject Y	Subject Z
Form A Before	72	58	69
Form B After	61	58	60
Form C Before	47	71	72
Form D After	58	70	86
Total for Series	238	257	287

the scores on all the forms of the Wylie Opposites Tests taken by Subjects X, Y, and Z during the four days of the fatigue series. For Subject X the differences between the scores made before the 12-hour periods of mental multiplication and those made after the mental multiplication periods, ranged from minus 11 to plus 11. For Subject Y the range was minus 10 to plus 14, and for Subject Z, minus 13 to plus 14. Not one of the subjects was consistently higher or lower, respectively, in her scores before or after the 12-hour mental work periods. Accordingly, the Wylie Opposites Tests did not provide a sensitive enough measuring device to justify any conclusions relative to transferred fatigue. The lowest score, 58, made by any of the subjects during the experiment, using the standardized Forms A, B, C, and D, ex-

cept for one score of 47 on Form C cited below, was higher than the median for third year college students, as given in the table of standards by Wylie. If the scores on Forms A, B, and D had been as low as this score of 47 on Form C, the total would have been 188 for the four forms. The median for college freshmen is 195. The highest score made on the Wylie Opposites Tests: A, B, C, and D was 88 on Form D. If this score had been taken for the four forms, the total would have been 352. For superior adults with special training in English, a median score of 290 is suggested by Wylie. On the other hand, the lowest score after work, on any of the four days was 58. If this score had been assumed for the other three tests as well, the total would have been 232, which would be nearly as high as the median,

240, for college seniors. Therefore, even the lowest score made after the 12-hour mental work periods, did not show any serious aberration in mental ability. Total scores made before and after the 12-hour periods of mental multiplication by subjects X, Y, and Z for the series of standardized Forms A, B, C, and D were the following:

<i>Wylie Opposites Test</i> Forms A, B, C, D		
Total of Scores for Series		
<i>Subject</i>	<i>Before</i>	<i>After</i>
X	261	258
Y	250	267
Z	300	302

Since Subject X lost only three points on this series following the periods of mental work, and Subject Z gained only two points, the rather considerable gain of Subject Y remained unexplained, but failed certainly, to reveal evidence of transferred mental fatigue.

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to determine, if possible, the effect of the continuous operation of mental multiplication of four-place numbers by four-place numbers for four successive 12-hour days upon certain other mental functions. Accordingly, certain mental tests were administered to the three Subjects, X, Y, and Z of this experiment for a period not exceeding twenty-five minutes both before and after the 12-hour periods of mental multiplication.

Results of the tests given before and after the 12-hour mental multiplication periods over the four-day fatigue series were not consistent enough to justify final conclusions. At the close of the first day, all the subjects made lower scores after the 12-hour period of mental work, the decrease ranging from 8 to 14 points, than they did on equivalent forms of the same tests taken before the 12 hours of mental work. These dif-

ferences on the first day seemed to indicate some transferred fatigue. On the second day, however, all three subjects made slightly higher, though not significantly higher, scores after the mental multiplication than before. On the third day, the erratic and even contradictory nature of the scores made both before and after the 12-hour period of mental work, may have indicated some transfer of fatigue. Sensory-motor coordination tests seemed somewhat more indicative of fatigue.

The results of the Artificial Language and Arithmetic Reasoning Tests, on the fourth day of the fatigue series, appeared to indicate that novel mental tasks requiring a high degree of organization and initiative were affected slightly, at best, by fatigue. That this fatigue was probably cumulative, was evidenced by the instability and unaccountable variation in the scores of both morning and evening tests on the third and fourth days. Tests that were repeated in identical forms all showed higher scores on the second performance with one exception. This improved performance appeared even when identical tests were repeated after the 12 hours of mental work. Hence the function of memory seemed to be significant.

Fatigue effects appeared to have been counteracted to some extent, at least, by the nervous stimulation which produced capacity production toward the end of the day, despite physical fatigue and mental boredom.

How much of the fatigue effect which was evidenced by inconsistent scores was due to transferred mental fatigue or to physical deterioration due to lack of food and exercise, cannot be evaluated. Neither should one assume to set the limits of individual endurance or safety as the result of the findings of this experiment.

CHAPTER III

PHYSIOLOGICAL CHANGES INVOLVED IN CONTINUOUS MENTAL MULTIPLICATION

THE PROBLEM

THE PROBLEM (1) was to discover whether or not definite physical signs of fatigue accompanied the mental multiplication of four-place numbers for a period of twelve hours on four consecutive days, with an added twenty-five minutes of psychological examinations administered both before and after the 12-hour mental multiplication periods. If these signs were measurable in terms of the tests used, to what extent did they appear?

Tests Used

Physiological tests recorded were changes in (1) abdominal and costal respiratory movements; (2) metabolic rates; (3) pulse, temperature, and weight; (4) blood content, as indicated by hemoglobin percentage, erythrocyte and leucocyte counts, and color index; (5) metabolic products, as shown by urine analysis.

The Experiment

Records of physiological processes were made on the day preceding and the day following the four-day fatigue series, and on each day of the fatigue series, at corresponding times of morning and evening. An eight minute period was allowed both before and after the 12-hour mental multiplication periods—these in addition to the twenty-five minute morning and evening psychological testing periods—for securing specimens of blood and urine, and recording weight, temperature, pulse, metabolic rate, and respiratory movements.

Materials and Equipment

Standard technical methods were used for determining weight, pulse, temperature, metabolic rate, urine analysis, and blood count. The Sanborn Graphic Metabolic machine for recording oxygen consumption was employed. Changes in abdominal and costal respiratory movements were made by the use of pneumographic belts arranged in such a manner that records were made on the kymograph drum.

The Experiment

Recordings of the present study extended over a period of six days, including not only the fatigue series, but also the day before and the day afterward. In a small room near the one equipped for problem solving, a comfortable cot was placed on blocks to make it level with the metabolic machine. A pillow and covers were provided, and the room temperature was maintained at approximately seventy degrees. In an adjoining room, equipment for blood and urine analysis was installed. Every test was systematized in order that as little discomfort as possible be suffered by the subjects.

Each subject ate breakfast before coming to the laboratory. Upon arrival at the laboratory, at approximately 5:00 A. M., each subject reclined for at least ten minutes to compensate for climbing the steps to the second story. Then the metabolic rate was measured on the Sanborn Graphic Metabolic machine, abdominal and costal respiratory movements were graphed, blood was taken, urine samples obtained, weight, temperature, and pulse recorded. The sub-

jects then went to the adjoining office for twenty-five minutes of psychological testing, and thence to the problem-solving laboratory. After a 12-hour period of continuous mental multiplication of four-place numbers without food, each subject returned to the office for another twenty-five minutes of psychological tests, followed by a repetition of the physiological tests of the morning. No exchange of conversation took place among the subjects or laboratory technicians until all tests of the day were completed. Not only were urine specimens obtained before and after each 12-hour period of multiplication, but also, as necessary, during the 12-hour periods. The subjects then went home to dinner and the night's rest.

Following the four-day fatigue series, the subjects returned both morning and evening for the physiological tests in order to determine any after effects.

RESULTS

Respiratory Movement (6)

The abdominal and costal respiratory graphs showed at the end of the first two days of the fatigue series, a considerable variation from the norms established for the same time of day in preceding records. Depth and amplitude of respiratory graphs were increased markedly for all three subjects; furthermore, the similarity between the curves of the first and second day was noticeable. At the end of the third day, the curves of the three subjects showed a return to the norms established on the day before the fatigue series was initiated. At the end of the fourth day, the curve of Subject X was almost identical with the norms established for Subject X on the day preceding the fatigue series, when no mental multiplication was performed. This return to the normal respiratory curve for

Subject X seemed to indicate that prolonged mental effort did not effect appreciably her respiration. Subject Y showed a slight change at the end of the fourth day, indicating slower and more labored respiration. Subject Z showed more even and natural breathing at the end of the fourth day than she had at the end of the first or second day. This data would indicate that long periods of mental work per se have very little effect upon respiration.

On the day following the fatigue series, respiratory graphs showed that the abdominal and costal breathing of all three subjects was practically the same as on the day preceding the fatigue series. Any transferred effect of prolonged mental work was not indicated in the respiratory graphs of Subjects X, Y, and Z.

Metabolic Rates

The metabolic rates shown in Tables 9, 10, and 11 represent those taken before and after a twelve-hour-and-fifty-minute period on each of the four days of the experiment, and also, on the day before and the day after, for purposes of checking against the normal rate.

On each of the four days of the experiment, the metabolic rates for Subject X were higher in the morning than in the evening. On the third and fourth days the rates were markedly higher than for the first two days. In the evening of the last day, the rate was much higher than for the evening of the other three days. A return to the levels of the first day was shown on the check day following the four day period. For Subject Y, the same phenomena held true, although her rate did not rise so high as the rates of the other two subjects. The check day showed a return to normal rates. Highest rates for Subject Z were registered in the

TABLE 9

METABOLIC RATE, PULSE, TEMPERATURE, AND WEIGHT RECORDINGS FOR SUBJECT X

Age 23—Height 62½ inches

Day	Pulse	Temp.	Barometric Pressure	Weight	Per Min. Actual Consumption Corrected*	Per Min. Normal Consumption Corrected*	Basal Rate
Check Day Before		None Taken					
1st A.M.	86	99.0	758 mm.	104¾ lb.	300 cc.	178 cc.	69
P.M.	72	98.4	758 mm.	104¾ lb.	250 cc.	178 cc.	41
2nd A.M.	88	98.4	758 mm.	105 lb.	275 cc.	178 cc.	55
P.M.	68	98.6	758 mm.	103 lb.	262 cc.	176 cc.	49
3rd A.M.	74	98.4	758 mm.	105½ lb.	469 cc.	178 cc.	163
P.M.	68	98.6	758 mm.	104½ lb.	235 cc.	178 cc.	31
4th A.M.	76	98.6	758 mm.	104¾ lb.	733 cc.	178 cc.	312
P.M.	70	98.6	757 mm.	101¾ lb.	431 cc.	175 cc.	146
Check Day After							
A.M.	86	98.6	757 mm.	101 lb.	266 cc.	175 cc.	53
P.M.	80	98.6	757 mm.	101 lb.	277 cc.	175 cc.	58

* Oxygen consumption.

TABLE 10

METABOLIC RATE, PULSE, TEMPERATURE, AND WEIGHT RECORDINGS FOR SUBJECT Y

Age 24—Height 62¼ inches

Day	Pulse	Temp.	Barometric Pressure	Weight	Per Min. Actual Consumption Corrected*	Per Min. Normal Consumption Corrected*	Basal Rate
Check Day Before							
A.M.	82	98.4	758 mm.	104 lb.	294 cc.	177 cc.	66
P.M.	92	98.6	758 mm.	104 lb.	262.5 cc.	177 cc.	48
1st A.M.	92	98.4	758 mm.	104 lb.	262.5 cc.	177 cc.	48
P.M.	88	98.4	758 mm.	104 lb.	287 cc.	177 cc.	42
2nd A.M.	80	98.6	758 mm.	103½ lb.	294 cc.	176 cc.	66
P.M.	84	98.6	758 mm.	100¾ lb.	287.5 cc.	175 cc.	64
3rd A.M.	88	98.6	758 mm.	102½ lb.	281 cc.	176 cc.	55
P.M.	80	99.0	758 mm.	100½ lb.	306 cc.	175 cc.	74
4th A.M.	84	98.6	758 mm.	102½ lb.	300 cc.	175 cc.	70
P.M.	88	98.6	757 mm.	99 lb.	281 cc.	173 cc.	62
Check Day After							
A.M.	86	98.4	757 mm.	101 lb.	225 cc.	175 cc.	28
P.M.	86	98.4	757 mm.	102 lb.	231 cc.	175.5 cc.	30

* Oxygen consumption.

mornings, with the last two days very much higher than the rates for the first two days. Despite these high rates on the third and fourth days of the experiment, the check day following showed a return to the normal rate. The increase in metabolic rates on the third and fourth days for Subjects X and Z probably indicated nervous tension stimulated by competition.

Pulse, Temperature, and Weight

These results are given in Tables 9, 10, and 11. Pulse rates for Subject X

of six and eight points, respectively, on the first and third days. Subject Z's pulse rates remained practically the same from morning to evening on each of the four days. Hence variations in pulse rate appear too slight to be significant.

The body temperatures of the three subjects were not affected by the experiment, remaining practically normal throughout the four-day series.

Loss of weight, however, was appreciable for each of the three subjects. This was due, probably, to the omission of the noon meal, the decrease in liquid

TABLE 11
METABOLIC RATE, PULSE, TEMPERATURE, AND WEIGHT RECORDINGS FOR SUBJECT Z

Age 30—Height 67½ inches

Day	Pulse	Temp.	Barometric Pressure	Weight	Per Min. Actual Consumption Corrected*	Per Min. Normal Consumption Corrected*	Basal Rate
Check Day Before							
A.M.	90	98.6	758 mm.	152 lb.	312.5 cc.	215 cc.	46
P.M.	86	98.6	758 mm.	152 lb.	325 cc.	215 cc.	52
1st							
A.M.	88	98.6	758 mm.	152 lb.	325 cc.	215 cc.	52
P.M.	86	98.6	758 mm.	150½ lb.	294 cc.	214 cc.	39
2nd							
A.M.	90	98.6	758 mm.	153½ lb.	319 cc.	217 cc.	47
P.M.	92	98.6	758 mm.	149½ lb.	300 cc.	214 cc.	40
3rd							
A.M.	90	98.4	758 mm.	150¾ lb.	512.5 cc.	214 cc.	130
P.M.	90	98.8	758 mm.	146¾ lb.	425 cc.	212 cc.	100
4th							
A.M.	90	98.4	758 mm.	151 lb.	1230 cc.	214 cc.	474
P.M.	90	98.6	757 mm.	148 lb.	529 cc.	212.5 cc.	148
Check Day After							
A.M.	86	98.4	757 mm.	148½ lb.	300 cc.	212.5 cc.	41
P.M.	86	98.6	757 mm.	148½ lb.	300 cc.	212.5 cc.	41

* Oxygen consumption.

were consistently lower every evening than they had been in the morning, with as much decrease as 20 beats on the second day. For Subject Y the pulse rate varied from an increase of four beats in the evening over the morning on the second and fourth days, to a decrease

intake, and to insensible perspiration, caused by nervous tension.

Changes in Blood Content

Blood samples were checked for per cent of hemoglobin, erythrocyte count, leucocyte count and color index. See

TABLE 12
BLOOD COUNT—SUBJECT X

Day	Hemo- globin	Erythro- cytes	Leuco- cytes	Color Index
Check Day Before	None Taken			
1st				
A.M.	62%	3,900,000	12,000	.79
P.M.	61%	3,800,000	10,600	.80
2nd				
A.M.	61%	3,850,000	7,000	.79
P.M.	60%	3,810,000	7,800	.75
3rd				
A.M.	61%	4,090,000	6,000	.74
P.M.	63%	4,240,000	9,400	.71
4th				
A.M.	61%	4,140,000	7,600	.73
P.M.	63%	4,100,000	9,300	.76
Check Day After				
A.M.	60%	4,050,000	8,000	.74
P.M.	61%	4,100,000	7,400	.72

Tables 12, 13, and 14. For Subject X, the hemoglobin per cent varied from 60%

TABLE 13
BLOOD COUNT—SUBJECT Y

Day	Hemo- globin	Erythro- cytes	Leuco- cytes	Color Index
Check Day Before				
A.M.	58%	4,450,000	7,000	.65
P.M.	58%	4,360,000	7,700	.66
1st				
A.M.	57%	3,910,000	6,300	.72
P.M.	59%	4,350,000	8,500	.67
2nd				
A.M.	57%	4,100,000	6,900	.69
P.M.	57%	4,020,000	8,300	.70
3rd				
A.M.	57%	4,120,000	7,200	.69
P.M.	59%	3,970,000	9,300	.74
4th				
A.M.	58%	3,970,000	8,200	.75
P.M.	60%	4,030,000	7,500	.74
Check Day After				
A.M.	59%	3,910,000	6,300	.75
P.M.	59%	3,810,000	7,600	.77

to 63%, which was not enough to be significant, and might even be attributed to technical method. This applied, also, to the erythrocyte count, in which the highest count was 4,240,000 per cubic millimeter, the lowest 3,800,000. The leucocyte count dropped from 12,000 per cubic millimeter to 10,600 on the first day, but on the three succeeding days, there were rises, respectively, of 800; 3,400; and 1,700. On the day following the fatigue series, the leucocyte count

TABLE 14
BLOOD COUNT—SUBJECT Z

Day	Hemo- globin	Erythro- cytes	Leuco- cytes	Color Index
Check Day Before				
A.M.	64%	4,000,000	5,000	.80
P.M.	64%	4,170,000	4,800	.76
1st				
A.M.	66%	4,250,000	7,000	.77
P.M.	66%	4,200,000	7,000	.79
2nd				
A.M.	64%	4,250,000	7,400	.75
P.M.	66%	4,230,000	8,700	.77
3rd				
A.M.	65%	4,430,000	6,100	.73
P.M.	66%	4,330,000	7,700	.76
4th				
A.M.	66%	4,300,000	9,700	.76
P.M.	66%	4,400,000	8,000	.75
Check Day After				
A.M.	66%	4,350,000	9,200	.75
P.M.	66%	4,260,000	7,500	.77

dropped 600 from morning to evening. Color index variation ranged from .71 to .79, depending on the hemoglobin and erythrocyte counts. These variations were not significant, for the leucocyte count normally rises in the afternoon.

The data for Subject Y were similar, the per cent of hemoglobin ranging from 57% to 60%; the erythrocyte count from 4,450,000 in the morning before the fa-

TABLE 15
URINE ANALYSIS—SUBJECT X

Day	Color	Appearance	Reaction	Specific Gravity	Sugar	Albumen	Acetone	Diacetic
Check Day Before	None							
1st	D	Cl	Neut.	2.000	N	N	N	N
	Y	C	Neut.	.700	N	N	N	N
	P	C	Neut.	.750	N	N	N	N
2nd	VP	C	Neut.	.850	N	N	P	N
	VP	C	Sl. Acid	.450	N	N	P	N
	P	C	Acid	.675	N	N	P	N
3rd	DY	C	Acid	1.275	N	N	Sl. P	N
	Y	C	Acid	1.070	N	N	Sl. P	N
	Y	C	Acid	2.040	N	N	Sl. P	N
4th	VP	Cl	Neut.	1.050	N	N	N	N
	VP	Cl	Acid	.950	N	N	N	N
Check Day After	DY	C	Acid	3.650	N	N	N	N

Note: D = Dark, Y = Yellow, P = Pale, V = Very, Cl = Cloudy, C = Clear, Neut. = Neutral, N = Negative, P = Positive, Sl. = Slightly.

tigue series, to 3,810,000 in the evening of the day following the four days of mental work; the color index varying from .65 on the day before the experiment, to .77 on the day following. The leucocyte count remained always within the normal limits of 5,000 to 10,000 per cubic millimeter, but showed a marked rise in the evening count over the morning count, except on the last day of the experiment, when the morning count was 8,200 and the evening 7,500.

Subject Z registered no changes, except those within the normal limits. The per cent of hemoglobin varied from 64% to 66% during the whole tested period.

Considering all the data obtained, there were no deviations from the normal of sufficient significance to warrant a conclusion that fatigue was registered in the blood.

Changes in Urine Analysis

The urine was examined for indications of fatigue, as waste products from

body metabolism are excreted through this medium. Color, appearance, specific gravity, presence of sugar, albumen, acetone, and diacetic acid were noted. From a study of Tables 15, 16, and 17, for Subjects X, Y, and Z, one may readily observe that the only factor which appeared as a deviation from the normal, was the appearance of acetone. This, probably, was caused by a lack of carbohydrate sufficient to oxidize the burning fat. This can be accounted for by the fact that no noon-day meal was eaten. The high specific gravity, in a few instances, was influenced by lack of water intake. The variations from normal color and appearance, acid reaction, and specific gravity were not sufficiently wide to be indicative of fatigue. The sugar, albumen, and diacetic reactions were consistently negative.

Relations between Metabolic Rates and Per Cent of Error

Table 18 shows the per cent of digit error for each subject on each day of the

TABLE 16
URINE ANALYSIS—SUBJECT Y

Day	Color	Appearance	Reaction	Specific Gravity	Sugar	Albumen	Acetone	Diacetic
Check Day Before	Y	C	Neut.	.300	N	N	N	N
1st	Y	C	Acid	1.050	N	N	N	N
	Y	C	Acid	1.450	N	N	N	N
	P	C	Neut.	.950	N	N	N	N
	P	C	Neut.	.050	N	N	N	N
	P	C	Neut.	.050	N	N	P	N
	Y	C	Acid	2.050	N	N	P	N
2nd	Y	C	Neut.	1.150	N	N	P	N
	P	C	Acid	1.170	N	N	P	N
	P	C	Acid	.950	N	N	P	N
3rd	Y	C	Neut.	1.050	N	N	Sl. P	N
	Y	C	Acid	1.150	N	N	P	N
4th	Y	C	Neut.	1.170	N	N	Sl. P	N
	P	C	Acid	1.050	N	N	Sl. P	N
	Y	C	Acid	1.100	N	N	Sl. P	N
Check Day After	DY	C	Acid	1.750	N	N	N	N
	Y	C	Acid	2.400	N	N	N	N

Note: D=Dark, Y=Yellow, P=Pale, C=Clear, Neut.=Neutral, N=Negative, Sl.=Slightly, P=Positive.

TABLE 17
URINE ANALYSIS—SUBJECT Z

Day	Color	Appearance	Reaction	Specific Gravity	Sugar	Albumen	Acetone	Diacetic
Check Day Before	LY	C	Acid	.222	N	N	N	N
	D	C	Neut.	.080	N	N	N	N
1st	Y	C	Neut.	.950	N	N	N	N
	P	C	Neut.	1.000	N	N	N	N
	P	C	Neut.	2.000	N	N	N	N
	P	C	Neut.	2.500	N	N	N	N
	DY	C	Acid	2.000	N	N	Sl. P	N
2nd	VP	C	Neut.	.067	N	N	Sl. P	N
	VP	C	Neut.	.095	N	N	Sl. P	N
	VP	C	Neut.	—	N	N	Sl. P	N
	P	C	Neut.	—	N	N	P	N
3rd	Y	Cl	Neut.	1.450	N	N	Sl. P	N
	P	C	Acid	.650	N	N	Sl. P	N
	P	C	Acid	1.150	N	N	P	N
4th	Y	C	Neut.	.950	N	N	Sl. P	N
	P	C	Neut.	1.050	N	N	Sl. P	N
	Y	C	Acid	1.050	N	N	Sl. P	N
	Y	C	Acid	2.050	N	N	Sl. P	N
Check Day After	P	C	Acid	.600	N	N	N	N
	P	C	Acid	.350	N	N	N	N

Note: L=Light, D=Dark, Y=Yellow, V=Very, P=Pale, C=Clear, Cl=Cloudy, Neut.=Neutral, N=Negative, Sl.=Slightly, P=Positive.

TABLE 18
PER CENT OF DIGIT ERROR AND METABOLIC RATE

Day	Prob.	Total Fig. in Answer	Errors	Per Cent of Errors	Met. Rates	
					A.M.	P.M.
<i>Subject X</i>						
1st	90	640	68	10.63	69	41
2nd	101	808	82	10.15	55	49
3rd	114	912	136	14.91	163	31
4th	115	920	138	15.00	312	146
		3280	424	12.92		
<i>Subject Y</i>						
1st	62	496	46	9.27	48	42
2nd	79	632	69	11.70	66	64
3rd	92	736	110	14.04	55	74
4th	92	736	102	13.85	70	62
		2600	327	12.57		
<i>Subject Z</i>						
1st	80	640	47	7.34	52	37
2nd	97	776	79	10.18	47	40
3rd	106	848	127	15.09	139	100
4th	100	800	87	10.88	474	148
		3064	340	11.09		

fatigue series. Comparison of the metabolic rates with the percentage of error for each day, revealed a definite correlation between the increase in metabolic rate and the increase in per cent of error. For example, Subject X, on the first day, made 10.63% digit errors, concurrent with a metabolic rate of plus 69 (morning) and 41 (evening). On the fourth day, her per cent of error was 15% and the metabolic rates, plus 163 and 312. For Subject Y, the per cent of error ranged from 9.27% on the first day to 14.91% on the third day, with a metabolic rate ranging from plus 47 on the first day to plus 74 on the third day. Subject Z's per cent of error ranged from 7.34% on the first day to 15.09% on the third day, while the metabolic rate rose from plus 52 on the first day to 139 on the evening of the third day. Despite some inconsistencies in readings, the evidence points to a definite correlation between increase in metabolic rate and increase in per cent of error.

CONCLUSIONS

As a result of four consecutive 12-hour days at the task of mental multiplication of four-place numbers, Subjects X, Y, and Z of the present experiment displayed few conclusive signs of unusual physical fatigue as revealed in measurements of abdominal and costal respiratory movements, of metabolic rates, pulse, temperature, and weight recordings, of blood content, and urine analysis.

Depth and amplitude of respiration showed some increases at the ends of the first and second days, due perhaps, to the excitement of initiating the experiment, but a certain tendency to return to the normal distinguished the respiratory graphs during the third and fourth days, and was followed by a complete return to normal on the day following the experiment. Therefore, one might logically conclude that prolonged mental effort had little effect upon respiration.

Metabolic rates increased for all three subjects as the fatigue series progressed, but the rate of increase differed widely among the three individuals and bore an unmistakable relation to the degree of fatigue experienced by the subject. Subject Y, who made no attempt to compete in speed with Subjects X and Z, though gaining in metabolic rate from the first day to the third, nevertheless, maintained a relatively low rate as compared with Subjects X and Z, who obviously were competing with each other. Increase of metabolic rate was significant and distressing during the third and fourth days for Subjects X and Z, who without doubt, were working near the limit of their nervous capacity. Subject Z, because of illness in her family, was unable to sleep at night, except fitfully, which probably accounted for her high morning metabolic rates on the third and fourth days. A significant relationship between per cent of digit error or speed or both, and metabolic rate was established for all three subjects, though the correlation was far from perfect. Too consistent to attribute to any freak of chance, however, was the rise in metabolic rate accompanying the gradual increase in per cent of digit error and the acceleration of speed during the latter two days of the fatigue series.

Pulse rate was slightly affected, if at all, and bodily temperature, not at all by the four days of mental multiplication. Loss in body weight, resulting from lessened food and liquid intake, and also, from insensible perspiration, no doubt due to nervous tension, were among the more apparent, though less significant changes brought about by the mental work periods.

No other than normal changes in the blood content were observable, as indicated by the per cent of hemoglobin, erythrocyte count, leucocyte count, and color index of the Subjects X, Y, and Z.

Urine analysis revealed little evidence of physiological changes resulting from the fatigue series, but increase in fatigue products was shown by the presence of acetone, which was probably caused by the lack of carbohydrate intake sufficient to oxidize the burning fat.

Despite subjective states of physical fatigue and over-wrought nerves, recognized by all three subjects, the records showed little indication of physical fatigue except for the rise in metabolic rates during the third and fourth days of the fatigue series. Even these metabolic rates had returned to normal on the morning of the day following the experiment.

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APPENDIX

COMMENTS OF SUBJECTS X, Y, AND Z DURING THE FATIGUE SERIES

COMMENTS were typed verbatim from the original notations on the slips containing the problems as given and the answers as obtained by Subjects X, Y, and Z at the time of the experiment in April, 1930.

Some problems, of course, were solved without any comment; only the numbers of problems which did provoke comment are listed.

Despite many discrepancies and contradictions, "feelings" of fatigue paralleled in a general way, for all three subjects, the incidence of error. As "feelings" of fatigue or subjective states of boredom, weariness, or actual physical and nervous discomfort accompanied continuous effort and the increasing incidence of error, it followed that "feelings" were not mutually independent of actual physical and mental states. That they were not, however, accurate indices of efficiency or of physical well-being was evident in both cursory and scientific examination of such data as that presented in Table 19.

The data in Table 19 indicate that Subjects X, Y, and Z in their notations of the first day (notations were written independently by Subjects between the solutions of problems, just after answers had been recorded) that 26 problems had

seemed to one, at least, of the three, peculiarly easy to work. Of these, 20 problems were correct and 6 contained error. On the second day, 24 problems only were correct out of 43 noted as especially easy; on the third, 8 problems only out of 26; and on the fourth, 12 out of 23.

Of the problems noted by Subjects X, Y, and Z as particularly difficult to work, 13 out of 25 were correct on the first day; 11 out of 24 on the second day; 4 out of 15 on the third; and 7 out of 18 on the fourth day.

Of the problems which were worked under conditions of some mental confusion or physical discomfort so pronounced that it caused mental confusion, as cited by at least one of Subjects X, Y, and Z, 33 were correct out of 62 worked on the first day; 41 out of 95 on the second; 27 out of 73 on the third; and 23 out of 77 on the fourth. The phenomenon of mental confusion paralleled, on the second day, apparently, the increasingly difficult adjustment to the confining routine of the fatigue series; on the third day, the cumulative burden of continuous effort under supreme strain; and on the fourth, the resolution of some tension with the end of the ordeal in sight.

TABLE 19
SUMMARY OF MORE FREQUENT COMMENTS NOTED BY SUBJECTS X, Y, AND Z DURING THE PROLONGED MENTAL MULTIPLICATION OF FOUR-PLACE NUMBERS

	"Easy to Solve" Notation		"Difficult to Solve" Notation		"Mental Confusion" Notation		"Exterior Disturbance" Notation	
	Correct	Error	Correct	Error	Correct	Error	Correct	Error
1st Day	20	6	13	12	33	29	17	12
2nd Day	24	19	11	13	41	54	10	10
3rd Day	8	18	4	11	27	46	1	6
4th Day	12	11	7	11	23	54	2	1

Of the problems worked during some type of outside disturbance sufficiently annoying to provoke written comment by one or more of Subjects X, Y, and Z, 17 were correct out of 29 on the first day; 10 out of 20 on the second; one out of 7 on the third; 2 out of 3 on the fourth

day. The intensity of physical discomfort and growing mental haziness were so absorbing, apparently, during the third and fourth days, that few remarks were made concerning outside disturbances.

COMMENTS MADE BETWEEN PROBLEMS DURING THE FATIGUE SERIES—BY SUBJECT X

(Correct) refers to the answer.

(1 or more errors) means digits wrong in answer.

First Day

Problem Number

1. Feel well—not sleepy but somewhat tired—anxious to begin work. Just recovered from a cold. (1 error)
6. Lack of concentration on problem. (Correct)
7. Boy entered room and left. (1 error)
8. Peculiar problem when multiplying. (Correct)
10. Someone entered—I asked him to leave and almost forgot the “760” of answer. (1 error)
17. Had to rework part of problem to get a forgotten number in a partial product. (Correct)
18. Boys are mopping this room and talking!!! (Correct)
20. Lost part of problem. Do reworked part. (Correct)
21. Drank water—am hungry. (Correct)
22. Badly confused, worked part over but should have worked all of it. (1 error)
23. Re-working it. (Correct)
24. Still restless. (1 error)
30. Thought of other things. Miss Smull brought in orange juice. It's tempting. (Correct)
36. Use facial muscles too much! (Correct)
45. Lavatory. And drank more water. (Slightly hungry again and am restless but feel fine. (Correct)
50. Mother and Aunt Lulu brought broth—not going to take it. (Correct)
54. Thought of other things—returned to problem when I noticed it. (Correct)
60. Feel fine but sometimes take short vacations without intending to. (Correct)
62. Restless but feel well. (Correct)
63. Lavatory. Drank more water. (3 errors)
64. Lack of attention again. (2 errors)
66. Mother and Aunt Lulu here with more to eat. Won't. Not very hungry anyway. (Correct)
68. Drank water. (1 error)
69. Feel fine but am restless and find it hard to get much accomplished. Both harder to memorize and harder to work now. (2 errors)
70. Inattention again. (3 errors)
74. Drank water and closed door while working problem. (1 error)
77. Easy one. (2 errors)
79. Very restless. (2 errors)
80. Ran out of problems. (3 errors) (6:15 A.M. to 6:03 P.M.)

Second Day

Problem Number

3. Restless already but easy to work prob. Chair is hard. (Correct)
5. Easy to memorize. (Correct)
6. Have moved—am sitting on cot—it is softer than the chair. (Correct)
9. Something like last one. (4 errors)

10. Easy to memorize. Easy. (Correct)
12. Very slightly dizzy. (Correct)
16. Easy. (Correct)
19. Lost part of third partial product. (1 error)
20. Seems a little harder to do problems—some difficulty in memorizing partial products. (Correct)
21. Lavatory—no bottles. Got pillow for back. Drank one glass of water. (2 errors)
23. Miss Small in but didn't disturb. (Correct)
28. Harder to memorize this type. (Correct)
31. Little confusing with all low numbers. (6 errors)
32. Easy but is it right? (2 errors)
33. Another easy one. (Correct)
37. Drank glass of water. Forgot part of problem. (Correct)
38. Almost forgot. (1 error)
40. Lavatory and drank 1 glass of water. (2 errors)
43. Easy one. (1 error)
44. Another easy one. (Correct)
47. Forgot part of orig. prob. (Correct)
50. Lavatory—also drank one more glass of water. (2 errors)
54. Have had this prob. or at least most of it before. (Correct)
55. Easy to memorize but not easy to work. (1 error)
56. Have had part or all of this prob. before. (Correct)
57. Forgot part. (Correct)
58. Had it before—think it is wrong. (1 error—Same as 50)
59. Had problem similar to this yesterday. (1 error)
60. Forgot some. Seems hard not to remember all of prob. and partial probs. (Correct)
61. Miss S. and Aunt L. in room but would have been almost as hard to work prob. anyway. (Correct)
63. Am getting restless—until now have been much less restless today than yesterday. (2 errors)
64. Feel fine but don't seem to be able to do problems as well as I did this morning. (Correct)
65. Easier. (Correct)
67. Spoke to Miss S. asked for more probs.
71. Feel well. Muscles of face particularly around eyes and mouth feel drawn. (3 errors)
74. Dr. R. brought more probs. Only slightly disturbing (1 error)
75. Lavatory. (1 error)
78. Easy one. (2 errors)
80. Feel well—am not nearly as restless as yesterday—muscles of face still feel drawn. (2 errors)
83. Mrs. H. moving around. (Correct)
85. Restless—wringing hands. (Correct)
101. Forgot part. Feel fine—have been moving hands, etc., constantly for last 3 hours—not as restless as yesterday, however.

Third Day

Problem Number

17. For first time this morning thought of outside things while working probs. (2 errors)
20. Lost total of first two partial products—reworked to that point before going on. (1 error)
21. Easy. (1 error)
27. Easy! Feel fine but seems to be harder to remember partial products than it was at first. (2 errors)
29. Lower figures are easier to use than larger ones. (1 error)
39. Lost problem when nearly worked—Miss S. here—asked for pillow. (1 error)

40. Drank water while working prob. (2 errors)
45. Lost part of probs. and reworked first part while trying to remember third partial product. (Correct)
50. Have had this problem before and am sure I made a mistake in working it before—made it difficult to work this time. (1 error) (Same as No. 40)
49. Before? (4 errors) (Same as 39)
56. Did not pay attention to prob. all the time. (Correct) (9 min. 20 sec.)
70. Drank water. (Correct)
73. Dr. R. here. Spoke to him. Forgot about zero. Facial muscles sore and drawn. Throat feels tight. (2 errors)
77. Have had this before. (Correct—same as 57)
78. Lack of strict attention. (1 error—7 min.)
81. Lack of attention again. (2 errors—9 min. 5 sec.)
87. Have very slight headache. It is exceedingly difficult to remember the numbers of the prob. and partial products. The numbers do not stand out clearly—I have a feeling of grasping them tight to prevent their slipping away. (1 error—10 min. 30 sec.)
88. Am lying down to see if that will help. Every time I worked a partial product over I got a different answer and in the meantime I lost the rest of it. I am trying to push myself but so far it hasn't had any effect. (Correct—14 min. 45 sec.)
89. Slight headache. (1 error—8 min. 35 sec.)
90. Feel better now. (Correct—9 min. 10 sec.)
95. Sitting up again. (Correct—3 min. 45 sec.)
99. Lavatory and drank a glass of water. Have felt better this past hour than during preceding hour. I do not have a headache but there is a feeling of heaviness. (1 error) (114 probs. solved)

Fourth Day

Problem Number

9. Have to use devices already—such as 365 equals days in the year, etc. Are these problems a repetition of some on a preceding day? Seem familiar. (Correct)
14. I feel as if I were not doing these problems as rapidly as I did yesterday but I seem to be getting almost as many done. (1 error)
15. Did I find a mistake or make one? (4 errors)
16. Lavatory. (2 errors)
20. In working problem this time I made a mistake but remembered partial product I had in same problem before so checked and found error. (3 errors—same as 16)
22. Easy. (2 errors)
24. Easy. (Correct)
28. Before. (Correct—same as 21)
37. Difficult. (Correct)
40. Before. (1 error—same as 35)
41. Something wrong. (2 errors)
45. Before. (Correct—same as 31)
46. Before? (2 errors—no duplication)
47. Lack of strict attention. Thought of other things during prob. (Correct)
48. Lavatory and drank water. Rather hungry. Feel fine. Not as tired as earlier in the day. (3 errors)
50. Thought of other things. (1 error)
51. Lost part—had to rework first partial prod. (1 error)
57. Thought of other things—got off by trying to find a connection by which to remember a partial product. Whenever there is no inherent connection in the number series I hunt an outside association such as “23” is my own age, etc. (4 errors)
58. Made mistake in problem when doing it before—perhaps made another one this time, too. (2 errors)

61. Lost part of problem—whole of first two partial products—reworked them. (1 error)
62. Stood up while working this one. (Correct)
63. Difficult. (Correct)
69. Dr. R. here—difficult to keep prob. with interruption. (Correct)
78. Slightly hungry. (1 error)
80. Difficult because not usual form; 1's and a zero. (Correct)
83. Difficult. Feel fine. (1 error)
88. Watch stopped during this problem. Reset it. (2 errors)
89. Feel much better than yesterday. No headache. Not "hazy." (1 error)
94. Slightly hungry but feel fine. Not difficult to work probs so far today. (Correct)
99. Probs that are identical or similar to previous probs are often confusing to work. (2 errors—same as 85)
100. Some difficulty in remembering partial products on this one. Drank glass of water. Corrected hours—had used 6 instead of 4. (1 error)
105. Still feel very well. Have not felt bad at any time during the day. No headache and no great difficulty in working. (3 errors)

COMMENTS MADE BETWEEN PROBLEMS DURING THE FATIGUE SERIES—BY SUBJECT Y

First Day

Problem Number

6. Water was brought in. (Correct)
11. Boys mopped the floor. (Correct)
12. Worked problem over because I got 2 numbers twisted (1 error)
13. Went to lavatory. Forgot one number in multiplier and had to start over. (1 error)
21. Forgot and started over. (Correct)
23. Laughter of boys and all of us. Hard to remember. Easier to remember near the end (2 errors)
24. Harder to hang on to all the numbers. (2 errors)
25. Easier to remember all the way through. (Correct)
26. Easier to remember than 15 minutes ago. (1 error)
31. Went to lavatory. (1 error)
34. Lay down. (Correct—12:30)
38. Mother came in to bring soup. (2 errors—19 min. 40 sec.)
42. Lights turned off. (2 errors)
43. Very hungry. (1 error—2:10)
48. Getting fidgety. (2 errors)
51. Orange juice brought in. Some talking, but not to me. (Correct)
52. This went more easily. (Correct)
53. Getting easier. (1 error)
54. Went to lavatory. (Correct)
63. Thinking about the end—Hard to remember multipliers. (4 errors)

Second Day

Problem Number

16. Water was brought in. (Correct)
17. Mind wandered. Examined specimens in the lab. (1 error)
18. Water. (Correct)
22. Forgot and started over twice. (Correct)
25. Lavatory—Drank more water. Head over right eye aches a little. (1 error)
29. Forgot and started over when I was nearly through. Boy came in and walked around (4 errors)
30. Problems seem harder to do. (Correct)
33. Forgot and did part of it over. (2 errors)
41. Forgot—started over. (1 error)

- 42. Forgot near the end and started over. (4 errors)
- 46. Forgot—did part over again. (1 error)
- 47. Interrupted! Arrival of soup! (1 error) (Did not eat it)
- 52. Started over. (2 errors)
- 53. Lavatory—Talked to Miss Small. Head feels rather stuffy. Still aches over right eye.
Forgot and had to look at prob again. (1 error)
- 54. Hard to remember. (Correct)
- 56. Water. (1 error)
- 57. Headache is getting more bothersome. (2 errors)
- 72. Getting easier to remember. (1 error)
- 73. Water. (1 error)

Third Day

Problem Number

- 9. Getting harder to remember. (Correct)
- 15. Dates—Easy to remember. (Correct)
- 20. Started problem all over because I was multiplying wrong numbers. (2 errors)
- 27. Dates—wars. (2 errors)
- 29. Forgot—multiplied by wrong number. Went over part of it. (1 error)
- 30. Water. (1 error)
- 33. Water. (1 error)
- 38. Water—Lavatory. (1 error)
- 43. Dates—war and Ind. (1898-1776—Correct)
- 49. I think I had this one before. (1 error—same as 39)
- 50. Had this before. (Correct—Same as 40)
- 52. Zeros mixed me for awhile. (5 errors—2 zeros in prob.)
- 53. Recognized this one. (4 errors)
- 57. Dates—Wars. (1 error)
- 60. Seemed familiar. (Correct—same as 29's multiplicand)
- 75. Dates. History. (1 error)
- 77. Dates. Same as one before upside down. (Correct—same as 57)
- 80. Dates. (1 error)
- 81. Lavatory. Water. (3 errors)
- 85. Multiplied by wrong number and had to start over. (1 error)
- 89. Hard to keep it in hand. (Correct)
- 90. Hard to keep numbers in mind. Forgot one number for awhile. (1 error)

Fourth Day

Problem Number

- 20. Duplicate. (2 errors—same as 16)
- 28. Duplicate. (1 error—same as 21)
- 40. Duplicate. (2 errors—same as 35)
- 45. Duplicate. (1 error—same as 31)
- 46. Hard to keep at this one—Numbers got lost. Changed from chair to bed. (2 errors)
- 47. Harder to keep concentrating on the prob. (6 errors)
- 50. More difficult to remember. Exasperating. (4 errors)
- 51. This was easier. (Correct)
- 69. Duplicate. Forgot and multiplied wrong number—3 instead of 6 to begin. Started again. (1 error—same as 60)
- 70. Mind wandered. (Correct)
- 74. Forgot and started over. (1 error)
- 80. Dates. Lavatory. Water. (Correct)
- 89. Hard to keep in mind. (1 error)
- 92. I knew this was the last and it seemed as though it would never end. (1 error)

COMMENTS MADE BETWEEN PROBLEMS DURING THE FATIGUE SERIES—BY SUBJECT Z

Abbreviations

(C)—Correct answer

Figures, such as 3-05—time in minutes and seconds for solving problem

2 errors, etc.—number of digit errors in answer

*First Day**Problem Number*

1. Easy memory. (C) (3-05)
8. Feel sleepy. Table too low, hurts back. Memory difficult. (C) (5-40)
9. Difficult memory. (C)
11. Feel I am making good progress. Chair uncomfortable. Nose bothers. (C)
12. Time out to lie down on bed. Easy problem. (C) (3-40)
13. Time out; uncomfortable. (C)
14. Disturbed; Miss Smull nurse in attendance lighted stove. Problem easy. Time out to get fixed more comfortably. (C)
15. Time out for nose and drink. Easy but forgot figures. (2 errors)
16. Easy problem. (C) (3-10)
17. Time out to adjust stove. Easy memory but mixed digits and had to rework. (C)
18. Easy problem. (C)
19. More difficult but problem easy to remember. (1 error)
20. Easy problem. Disturbance—boys talking and mopping floor. Can't work with talk. (C) (8-20)
21. Easy, but too many noises. (C) (5-50)
22. Time out, lavatory. Hard to recall numbers—day dreaming. (C)
23. Lazy. Forgot. (C) (10-10)
24. Difficult to recall—day dreaming. (1 error)
25. Easy. (C) (2-55)
26. Easy, but I forgot. (C) (8-30)
27. "0" makes problem easier. (C)
28. Hard to remember problem. (2 errors)
29. Can't remember original problem as well as at first. (C)
30. Easy, but I can't remember anything. (C) (8-55)
31. Easy problem. No memory needed for original problem. Time out a minute. (C)
32. Not sure of answer. (3 errors) (9 minutes)
33. Problem hard to remember. (C)
34. Problem difficult to remember. (1 error)
35. Time out to drink orange juice, also lavatory. In cross multiplying, digits get confused. Problem easier to remember. (C)
36. Distinctly remember problem. Am sure answer was altogether different. Looking back to satisfy my curiosity. Can't find it. (1 error)
37. Problem difficult. (C) (6-15)
38. Problem difficult to recall. (2 errors)
44. Clock great annoyance when it strikes. Writing this now lest I forget. Forgot problem; had to rework. (2 errors) (8-35)
46. Problem difficult; beginning to feel lazy mentally. (2 errors) (11-55)
47. Problem easy. I'm not so good. (C)
49. Time out, lavatory. So angry I can't think. Provoked because I drank orange juice. (2 errors)
50. Suspect this answer wrong. Eyes hurt from strain. (1 error)
52. This problem like one done previously. Digits in it were 3264

 ×4925

(Number 47 like this). (C) (4-55)

53. Disturbance. Mrs. Harker brought in food to tempt us. (1 error)
54. Won't guarantee this answer. (1 error)
55. Problem difficult to remember. (C)
56. Beginning to draw muscles of face when can't recall. Problem very difficult. (1 error) (11-30)
57. Perhaps my way of working the problems makes this one difficult. Terribly difficult for me. (1 error) (10-50)
58. Recall very difficult; feel muscles of forehead pulling. (C)
59. Time out to close door. Another hard problem. (C)
60. Remembered problem because $18 \times 2 = 36$. Answer seemed wrong to me. Very difficult problem. (C)
61. Had hard time getting this problem; eyes hurt so badly that they hindered. (C) (12-10)
62. Time out. Lavatory. Problem out of place when I returned. Zeros made problem easy. (3 errors) (5-20)
63. Problem seemed familiar; do not recall answer. (1 error)
64. Should have worked problem more quickly. Eyes chief hindrance. (C)
65. Problem should have been worked more quickly. (3 errors)
66. Can't remember—eyes hurt. (C) (15-20)
67. Light makes eyes burn. Can't work efficiently. Too tired sitting. (C)
68. Think I must have caught cold in eyes. (1 error)
69. Disturbance; more food brought in to tempt us. (2 errors)
70. Forgot several times. Problem may be wrong; not any too sure. (C)
71. Fatigue beginning to show in blank mind. Many times combinations disappear completely. When I am beginning a day's work, I never forget; only after I have tried many problems does this phenomenon appear. (C) (5-50)
72. Mind a complete blank several times. Problem not easy to associate. Simply cannot remember. (C)
73. With great effort speeded up a little. Answer may not be correct. (1 error)
74. Don't feel sure about answer. Combinations left me several times. (1 error)
75. Too tired to think (1 error)
76. 58-68 combination easier. (C) (6-20)
77. Loafing. Hate to do this now. (1 error) (12-40)
78. Slips stacked upside down. 62-52 combination easier. (C)
79. Problem easy. Should do it in 3-4 minutes. Sleepy. (C) (7-10)
80. Problem easily worked. Time does not show strain under which problem was worked. (C) (11-00)

Second Day

Problem Number

6. Not too sure of answer. May have confused digits. Easy problem, nevertheless. (1 error) (5-30)
8. Answer not too sure. (C) (4-00)
9. Problem easy but I kept forgetting combinations in original problem. (C)
10. Combinations stick without memorizing them. Easy problem. (C) (3-50)
11. Problem easy, but I confused answer. (2 errors) (4-40)
12. "0" makes problem simpler except that it causes a little thought as to what to do with it. (C) (4-40)
13. Lavatory. (C)
14. Problem very easy; but I am lazy. (C) (4-50)
15. I take a mental vacation everytime the clock strikes. Problem very easy, but I forgot answer. (1 error)
16. Easy; I should have done it in half time. (C) (5-20)
17. Knew answer wrong. Reworked. (1 error) (8-25)
18. Frequently used fingers to recall digits, especially when memory failed. Problem difficult. (1 error)

19. Difficult answer. (1 error)
20. Time out to fix bed. Had to rework three or four places in answer. (C) (11)
22. Consumed glass of water. Problem easy to remember but answer is big number. (2 errors) (4-40)
23. So easy that I got mixed up on the 1's. (C) (5-0)
24. Difficult. (C) (7-35)
25. Not sure of answer. Don't feel like reworking. (2 errors)
26. Have headache—quite a bad one. Answer probably incorrect. (C) (10-)
27. Beginning to feel that I may not be able to last out the day; headache too bad. (1 error) (5-50)
28. Time out. Lavatory. (C)
29. Problem seemed difficult. (4 errors) (6-40)
30. Disturbance. Mrs. Harker brought food again! (C)
31. Problem very easy but my head aches too dreadfully to do it. (C) (7-45)
32. Not sure my answer is correct. (C) (3-15)
Fellow came in and "scared the wits out of me."
33. Problem easy, but had to rest my head a minute. (1 error) (8-00)
34. Should do this in 2 minutes if I felt well. Answer easy to remember, so also the original problem. (C) (4-30)
35. Problem very easy, but my head is crazy. (2 errors) Pains in temples. (4-35)
37. Feel a little better now. (3 errors)
38. Recall not so bad, but pains in head hinder. Problem fairly easy. (4 errors) (6-45)
39. Feel hungry and a little shaky. Answer seems incorrect. (C)
40. Day dreaming. Problem dreadfully easy; I should have done it in less than half time. (1 error) (4-40)
41. Figures in place of "69" hardest for me to remember usually. Difficult, but I believe answer is correct. (C) (9-10)
42. Lavatory. (C)
43. So easy that I became tangled up in the 1's. So amused at "1899" (year of my birth) that it hindered. Not sure of answer. (1 error) (4-25)
44. Answer easy to remember, but it probably is wrong. (1 error)
45. Hard problem. Forgot answer several times. (1 error) (11-10)
46. Numbers disappear entirely. Almost physical effort to recall them. Should have worked more quickly. (2 errors) (6-20)
47. Forgot "4" in answer. Had to rework. (C) (8-50)
48. Difficult to memorize. (C) (7-10)
49. Feeling better. Don't seem tired at all, but I don't have any "pep." Sometimes when something adds up to 0, the satisfaction nearly causes me to forget the whole thing. (C) (5-30)
50. Problem easy, but I forgot it. Believe I'm sleepy. (C) (10-45)
51. Don't know why time wasn't longer—seemed like an age. (2 errors) (8-55)
52. Went to sleep for a second; almost forgot everything. Awakened by Mrs. Harker bringing in food. (Alas! we can't eat it.) (3 errors) (10-55)
53. This may be the answer, and it may not be; I'm not responsible from now on. (1 error)
54. Drinking glass of water. (C)
55. Have doubts about these numbers. (1 error)
56. Most of the problems along here seem familiar to me. Did we have them yesterday? (C)
58. Should have worked this much more quickly. Stopped to check answer. (Same problem as No. 50) (C) (4-30)
59. Had numbers interchanged in answer; stopped to check. (2 errors) (7-20)
61. Think these are wrong, but I can't get the numbers straightened out. (C) (8-55)
62. Time out. Lavatory. This problem seems familiar. I think I remember some of answer. (C) (7-40)
63. Easy problem. Head working a little better. (C) (3-10)
64. Easy. (1 error)

65. Easy problem. Disturbed by entrance of people. (2 errors) (6-10)
66. Easy problem, but I am too tired to gain speed. (C) (5-10)
67. Easy problem, but I can't remember anything. (C) (9-00)
68. Scarcely can remember any numbers. (C)
69. Lost watch in bed. Drank glass of water. (C) (9-00)
70. Decided to do 100 problems before I go—maybe. Answer seems wrong. (2 errors) (8-15)
73. Tried to work at maximum speed. (C) (4-35)
74. Can make fairly good speed but with terrible effort. Not sure of numbers; people enter room. I am trying to speed up. (1 error) (3-15)
75. Time out to fix shades. (C)
76. Working like fury—didn't think I could do it. (2 errors) (3-15)
77. Answer easy—that is, if this is it. (It was) (C) (4-30)
78. Seem to have struck second wind. Eyes a little tired. Easy problem. (C) (3-45)
79. This effort will kill me, I'm afraid. (2 errors) (4-00)
80. Feeling better to begin with than I expected. Forgot to turn problems over; did this one first. (1 error) (3-45)
81. This problem looked harder. (2 errors) (5-40)
82. Feel wonderfully fine considering. What can have struck me? Hard to remember number. (C) (4-30)
83. This isn't half bad; but I'm glad there are just two more days. Problem fairly hard to recall. (C) (7-30)
84. Problem hard. I'm going to work like a demon until 6:20 just to see if I can. Answer correct? (1 error) (5-35)
85. Time out to sharpen pencil. Am making terrible wrinkles in my face trying to think like this—once in a lifetime! Getting lazy. Day dreaming (1 error) (7-10)
86. Not too sure answer is correct. Easy problem to remember. (1 error) (4-00)
87. Can't hurry as much as I try. (1 error) (5-10)
88. Too tired to speed up. Nervous—shaky. (C) (7-0)
89. I'll never make that 100 at this rate. Once more; here goes. A tough problem! (1 error) (6-30)
90. Another horrid one. I don't believe it pays to strain so much. Maybe I won't be able to do anything tomorrow. Not so bad for a time. (C) (5-30)
91. 83 and 38 helped me remember. Problem hard otherwise. (3 errors) (7-10)
92. Problem easier. (1 error) (5-50)
95. Doing fairly well, I think. (1 error) (6-05)
97. Can't do 100 today. (2 errors) (14-15)

Third Day

Problem Number

1. Have not slept soundly for 3 or 4 nights. Slept none after 12 P. M. last night. (C)
3. Time out to fix seat. (2 errors)
5. Easy problem. (C)
6. Harder problem to memorize. (2 errors)
7. Clock struck and made me forget. (1 error)
11. Doubt this answer; became confused in cross multiplication. (C)
12. Harder to remember. (1 error)
14. Easy problem, but I lost track in answer. (4 errors)
15. Easy. "0's" and "1's" confusing. (C)
17. Forgot problem. (C)
18. Problem terribly difficult for some reason. (4 errors) Hard to memorize.
19. Easy. (1 error)
20. Harder. (C)
21. Big numbers in cross multiplication. (1 error)
23. Answer easy to remember. (2 errors)

24. Lost track of numbers in answer; had to locate error. (C)
25. Got stuck; had to recheck answer. (1 error)
26. Hard to memorize. (3 errors)
27. "Ones" confusing. Yet—not sure it is correct. (3 errors)
28. Easy. (C)
31. Problem easy; forgot answer. (C)
32. Time out a moment. (1 error)
33. Bell on clock disturbed just as I started to write answer. (C)
34. Easy problem. (1 error)
35. Have no memory at all. Forgot "0" for a long time. (1 error)
Problem so much like one before! (No. 34 was similar)
36. Very difficult. Had to carry "23" etc. (C)
38. Went quickly but may not be correct. (1 error)
39. Time out; lavatory. (1 error) Same problem as yesterday or day before, I think.
40. Hard as the dickens. Probably incorrect also. (3 errors)
42. Forgot answer. (1 error) Goal 100 problems today.
43. Problem easy but couldn't remember answer. (1 error)
45. Hard problem. (1 error)
46. Forgot answer. (2 errors)
47. Had problem a long time ago but rechecked answer. It was correct this time. (C)
48. Afraid answer is incorrect. (3 errors)
49. Should have done this in half the time. (C) (7 min. 15 sec.)
50. Answer gone but problem is same. (3 errors) (Same as 40)
51. Seems all wrong yet. (1 error)
52. "0" confusing. Think answer is probably wrong. (1 error)
53. Had same problem yesterday. Moved. (C) (Numbers 68, 64, and 31 on second day were similar.)
55. Answer easy to remember if it is only right. (3 errors)
56. Time out for lavatory. Won't guarantee answer. (C)
57. Easy but I'm beginning to lag. Had this yesterday or day before. (2 errors) (On second day the "1914" in problem 43 was same.)
58. Think this is wrong! Too tired to check. (1 error)
59. Getting more indolent every moment. (1 error)
60. Hard; but I'm tired. (C)
61. Time wrong on others, I think. (1 error)
63. Time out; lavatory. (1 error)
65. Time out to shut off lights. (1 error)
67. Forget everything. Easy problem, but I just can't do it quickly now. (1 error) (3-45)
68. Wish I could speed up. Simply can't do it. (C) (4-45)
69. Recall with greatest difficulty. Can't remember figures. (C)
70. Getting tired to the point of inability to work these. Don't see how I can finish the day.
(C) (3-55) 1: 54 P.M.
71. Time out to go to table. Doubt answer is correct. (2 errors)
72. How did I do it? (2 errors)
73. Easy. But "0's" always present obstacle. (2 errors)
74. Too easy not to confuse. (2 errors)
76. Thought I would never finish it. (2 errors) (7-30)
77. Easy. (3 errors)
78. Suspect this answer is all wrong. My head is not functioning properly. (1 error)
80. So easy that I had to do it again. (C)
81. Speeding up. I've done this problem before, I think. (2 errors)
82. Not sure of answer. Hazy. (2 errors)
83. Hurrah! (1 error)
85. Had doubt about 2 figures in answer, but refuse to remove it! (2 errors)

86. Slow! Can't think. (C) (4-30)
87. Answer hazy. (4 errors)
88. Terrible. Forgot answer. (2 errors) (11-35)
89. Time out. Lavatory. Answer hazy. (3 errors)
90. Well done for time. Accuracy? (C) (5-30)
93. Hard luck. Forgot about 10 times. (C)
95. Familiar problem. Forgot number in answer. (C)
96. I remembered this answer, I thought. (2 errors)
97. Big numbers to carry. (1 error)
98. Time out, lavatory. (1 error)
99. Mind fresh after little walk. Either I'm feeling better or I am so far gone that my mind's clear momentarily. (3 errors)
100. Good for this one. (2 errors)
101. Afraid I did it too quickly. (1 error)
102. Forgot answer. Too hard to rework. (2 errors)
104. Time out to turn on light. Getting very tired. I can scarcely remember a figure. Looked at problem 4 or 5 times. (1 error)
105. Just can't tackle another; feel that I might break. Suppose I wouldn't though—here goes. (C)
106. Darn it; I have to do this one. (1 error)

Fourth Day

Problem Number

1. Thought of mistake I made in reasoning test which preceded this multiplication. Answer should have been 1000 instead of 1100. Fussed because I made so many mistakes. (2 errors) Can scarcely see. Slept three hours last night after about three nights with no sleep.
3. Time out; lavatory. (1 error)
5. Day dreaming; I'll have to do better than this. (C)
6. Don't feel like working. (2 errors)
7. Keep thinking of mistakes I made in tests preceding this ordeal. It bothers. Problem difficult also. Better time. (1 error) (5-5)
9. Made note. (2 errors)
10. Answer easy to remember. (C)
11. Forgot answer twice. Time out; lavatory. (C)
12. Problem very easy; loafed on job. Forgot answer. (1 error) (6-30)
13. Problem easy, but I'm tired. Forehead seems to have developed reflex. (2 errors)
14. Reflex in forehead pulls. (1 error)
15. Forgot about x times. Answer still hazy. (2 errors)
17. Hard problem. (C)
18. Not sure of answer. (C)
19. Good work! For me it is now. (C) (4-45)
20. Answer seems wrong! Won't rework! (1 error)
21. Combinations are becoming more familiar. (3 errors)
22. Easy. (4 errors)
23. Not so bad for 4th day. (1 error)
25. Easy. (C)
26. Good for a broken spirit. Easy though! Answer easy to remember. (C)
27. Afraid answer is not correct. (1 error)
28. I can think clearly but the muscles of my face are worn out. I am going on my nervous energy. (1 error)
29. Answer seems incorrect. (1 error)
31. Hard answer, and I forgot it—reworked. (C)
32. Hard to remember problem. Good. (1 error)
35. Repetition makes easier work. (1 error) Two 5's in multiplier.

36. Had answer all mixed up in my mind. (C)
37. Pretty good; don't feel so tired in thinking. Only facial muscles are lifeless. (1 error)
38. Time out; lavatory. (1 error)
39. "2's" easy. (1 error)
41. Forgot. (C)
42. Good! (C)
44. Forgot. (1 error)
45. Harder. (1 error)
46. Doubt answer. (C)
48. Beginning to feel hungry. (1 error) 12:03 P.M. Forgot answer.
49. Forgot answer. (1 error)
50. A hard problem. Did it quickly but pulling face and straining eye muscles are almost too much for me. (2 errors)
51. Forgot answer. (C)
52. Went daydreaming. Problem not hard. (C)
53. Good work. (C)
55. Easy but forgot. (C)
56. Not so bad; problem easy to associate. (3 errors)
57. Daydreaming. Forehead is getting wrinkles fast. (C)
58. Believe I will go insane after two or three more days of this. (1 error)
59. Hard to work; easy to remember. (C)
63. Forgot answer when Dr. Raubenheimer came in. Terrible problem. (1 error)
65. Forgot everything. (1 error) (9 min.)
69. Forgot answer. (C)
71. Time out; lavatory. (2 errors)
72. Easy. Answer easy to remember. (C)
76. Forgot answer. (C)
77. I seem to do this without any thinking; but the mechanized pulling of face and eye muscles is killing me. (1 error)
78. Confusing "0's". (1 error)
80. "0" bothered. (1 error)
81. Time out. (C)
82. "Ones" confusing. (2 errors)
83. Forgot answer. (2 errors)
84. Forgot answer. (1 error)
85. Want to hurry and can't. Reflex in my forehead twitches. (1 error)
87. Tough problem. (3 errors)
88. Thought I would never get it, not sure yet. (1 error) (9-10)
89. Think I have gotten the same answer before. (C)
91. All mixed up on answer. (1 error)
92. Answer probably wrong. (1 error)
93. Problem easier. (C)
94. Hard. (C)
95. Doubt if it is correct. Came so fast that I can't believe it. (4 errors) (5-10)
96. A terrible problem to give a weary person! (2 errors)
97. Want to do 3 more before 6 o'clock. (C) time out, lavatory.
99. Did this in a hurry; doubt if it is correct. (3 errors)
100. Finished 100 problems!

SUBJECT Z'S OBSERVATIONS WRITTEN
DOWN DURING THE WEEK FOLLOWING
THE FATIGUE SERIES

I think clearly and feel no physical exhaustion, but I seem to be a "nervous

wreck."

Local areas of the body are weary from long lying or sitting in one position.

A reflex developed in my forehead over my left eye by the end of the second

day. It continued through the fourth day of the fatigue series and remained to some extent until Sunday evening. (Yesterday) Forehead still feels weary at school today. (Monday)

So nervous that any loud or unnecessary noise—or teasing, angers me.

Slept only two or three hours each night.

From 1:30 A. M. on until 4 A. M. "saw" problems and worried over working them. Waited for alarm to ring at 4 A. M.

Took sleeping tablets on evening of second day, hoping to sleep; but they only caused my legs and arms to feel a little numb; my foolish brain kept right on.

Baby not well from whooping cough. Nervous chill passed all over me every time he cried out in the night. Not sure how he was in my absence.

Went to bed between 8 and 9 o'clock each night. Did not go to sleep until 10 or 11. Slept fairly soundly until about 1:30, except on second night; baby cried several times about midnight.

Nervous tension partly due to anxiety to make good showing on tests before and after each day of fatigue series.

Mechanical aptitude test and first arithmetic reasoning test worried me more than others. Presence of Dr. Raubenheimer contributing factor.

Could not work at maximum efficiency in earlier hours of day because of the discouraging thought of the number of hours ahead.

Picked up in speed about 2 or 3 o'clock each afternoon because of nearing end of day, I think.

Felt discouraged between 10 A. M. and 1 P. M. on second day—thought I should surely faint. Almost went to sleep.

Would have fainted, I believe, if I had given up control for one moment.

Was not sure on evening of third day that I would be able to work the 4th. Almost unbalanced nervously. Thought I should surely fall to the floor when I came down for metabolic test. Did mechanical aptitude test almost without thought. Didn't care whether I scored right or not because I knew I couldn't control my responses to any accurate extent.

Felt encouraged on morning of fourth day, because I began to believe that I would be able to finish; but decided to work at comfortable rate in order that I might compose my nerves.

Felt better at end of fourth day than at beginning of second, except that I was very shaky. Dreadfully happy that experiment was done.

Almost fainted at dinner table Saturday evening after fatigue series.

Conscious through all four days of increase of heart beat. At times this became a great annoyance to my work.

Had cold during first two days of experiment, not bad but my nose was "stopped" so that I could not breathe through it comfortably. This annoyed me greatly at night.

Had dreaded doing these four days for more than two years. Mental attitude toward entire experiment clouded by this dread.

Isolation, hard work, etc., made entire four days seem like one long nightmare to me. I marvelled that the other two girls seemed to hold up so well.

Would not repeat these four days for \$10,000, I believe.

Physical weakness due to overwrought nervous condition was most serious over-all effect of experiment on me.



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no. 5

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Huxtable, et al.

